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DEMONSTRATION OF SPLIT-FLOW VENTILATION AND RECIRCULATION AS FLOW-REDUCTION METHODS IN AN AIR FORCE PAINT SPRAY BOOTH

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This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*

During a series of painting operations in a horizontal-flow paint spray booth at Travis AFB, CA, baseline concentrations of four classes of toxic airborne pollutants were measured at 24 locations across a plane immediately forward of the exhaust filters, in the exhaust duct, and inside and outside the respirator in the painter's breathing zone (BZ). The resulting data were analyzed and used to design a modified ventilation system that (1) separates a portion of the exhaust exiting the lower portion of the booth, which contains a concentration of toxic pollutants greater than the average at the exhaust plane (split-flow); and (2) provides an option to return the flow from the upper portion of the exhaust to the intake plenum for mixing with fresh air and recirculation through the booth (recirculation). After critical review by cognizant Air Force offices, and an experimental demonstration showing that a flame ionization detector monitoring the air entering the booth is able to detect excursions above the equivalent exposure limit for the solvents in the paint, the exhaust duct was reconfigured for split-flow and recirculating ventilation. A volunteer painter was briefed on the increased risk of exposure during recirculation, and on the purposes and possible benefits of this study. He then signed an informed consent form before participating in the recirculation tests. A series of tests generally equivalent to the baseline series was conducted during split-flow and

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recirculating ventilation, and three tests were performed during only split-flow ventilation. Data from the two sets of tests show that pollutants concentrate toward the bottom of the booth during ordinary painting operations; that local processes associated with circulation near the paint spray gun contribute far more to the net exposure to the painter than do toxic pollutants in the recirculated air stream; and that, under well-ventilated conditions, including split-flow and recirculation of a large fraction of the exhaust air, equivalent exposures to airborne toxic pollutants (calculated as the sum of 8-hour, time-weighted concentrations of toxicants divided by their respective Permissible Exposure Limits) should not exceed 0.25 in the intake air. An economic analysis of costs to implement thermal or catalytic incineration, with and without flow reduction by split-flow and recirculating technologies, projects substantial savings, such that the payback periods for inclusion of flow-reduction technology during installation of the control device are about 1 year. The recirculation of air in the paint spray booth did not result in an increase in air contaminants that would exceed the capability of proper respiratory protection. The magnitude of the incremental increase in exposure derives primarily from particulates in the recirculated air. This is defined by the particulate removal efficiency of the particulate controls, which can be compromised by improper maintenance. However, with proper design, installation, and maintenance, the increment to risk is normally less than the round-off errors in the calculation of net job-related risk. Because the cost benefit is obtained at an increase of risk of exposure to painters, the acceptability of this cost-benefit tradeoff will have to be resolved by industrial hygiene functions at both policy and local levels before this advance can be implemented at Air Force installations.

SUMMARY

A. OBJECTIVE

The objective of this program was to demonstrate that split-flow and recirculating ventilation, individually and in combination, are safe and cost-effective methods of reducing paint spray booth exhaust flow rates to lower the costs both of conditioning intake air and of controlling volatile organic compound (VOC) emissions in exhaust air.

B. BACKGROUND

This study was part of an extended program of investigations into the cost and efficacy of innovative approaches for bringing U.S. Air Force industrial operations into compliance with current and anticipated air pollution environmental standards. Adequate ventilation of paint spray booths requires the movement of large quantities of air, which are slightly contaminated during passage through the booth. Air exhausted from this process requires decontamination, which, although technically achievable at operating flow rates, can be prohibitively expensive. Because emission-control costs depend on the volume of exhaust air being treated, considerable savings can be realized through the application of an acceptable flow-reduction method.

A first principle of industrial hygiene is to employ engineering controls to their limit before invoking personal protection. In dealing with exposures to airborne toxics, the mainstay engineering device is enhancement of ventilation. However, increased ventilation creates enormous volumes of slightly contaminated air, which must be treated before discharge and, in many situations, the cost of such treatment is excessive. In such circumstances, a judgment must be made about the relative cost in increased exposure compared to the economic benefit in decreased operating cost. The goal of this study was to provide experimental data to support the development of a general Air Force position and objective criteria for local decisions about the acceptability of using flow-reduction methods in paint spray booths, based on local health-risk/cost-benefit considerations.

C. SCOPE

This study comprised two sets of experimental measurements in Booth 2, Building 845, Travis Air Force Base (AFB), California, plus the results of an ancillary effort conducted at Research Triangle Institute (RTI) to verify experimentally that the flame ionization detector (FID) used in the ventilation control loop is within its linear response range at the equivalent exposure limit for the mixture of solvents present in the mixed topcoat. The first set of experimental measurements was a baseline characterization of the distribution of toxic pollutants at the exhaust face and in the exhaust duct of Booth 2. These data, the RTI results, and the test plan for the second set of tests were reviewed by HQ AFLC/SGBE before approval was given to proceed with the recirculation tests. The test plan and engineering drawings were reviewed by the Fire Department, Safety Office, and Civil Engineering Office at Travis AFB and approved before implementation. For the second set of tests, the ductwork in Booth 2 was reconfigured to separate exhaust streams from the top and bottom of the booth (split-flow) and to return the upper exhaust stream to the intake plenum for recirculation through the booth. The volunteer painter was briefed and signed an informed consent form before participating in the study. During separate painting sessions, several sets of concentration measurements were made of VOCs, particulates, heavy metals, and isocyanates. Equivalent exposures (E_m) were calculated from these data, and projections of E_m were made for a range of recirculation ratios, together

with an economic analysis of the corresponding costs to install flow reduction technology and apply VOC emission control devices.

D. METHODOLOGY

Per standard Travis AFB policy, painters in Booth 2 wear a protective jump suit, a separate hood, and an airline respirator. To determine exposure concentrations, sampling was performed simultaneously inside and outside the respirator, at 24 locations at the exhaust face, in the exhaust ducts, and, during the second set of tests, at three locations at the face of each of the two intake filters. To determine environmental contributions to the load of pollutants, background air samples were collected at the back of the booth prior to the release of any paint-derived materials. Standard sampling methods used were National Institute of Occupational Safety and Health (NIOSH) Method 1300 (integrated measurement of individual organic species), Bay Area Air Quality Management District (BAAQMD) Method ST-7 and U.S. Environmental Protection Agency (EPA) Method 25A (continuous measurement of total organic concentration), Occupational Safety and Health Administration (OSHA) Method 42 (filter faces and ducts) and NIOSH Method 5521 (painter and ducts) (isocyanates), EPA Method 5 and NIOSH Method 500 (particulate), and EPA Draft Multiple Metals and NIOSH Method 7300 (metals). Paint usage was determined by weighing the gun after each filling and at the end of each painting session. The percent volatile content of the paint was determined gravimetrically, as percent weight loss to evaporation. Airflows were measured with an anemometer (American Conference of Governmental Industrial Hygienists [ACGIH]) in the booth and with a pitot tube (EPA 2) in the exhaust ducts. Painting start and stop times were recorded manually by an observer, stationed at the rear of the booth, who also noted the dimensions and locations of workpieces painted, coatings applied, and other details. Projections of equivalent exposures at different recirculation ratios were calculated by a Lotus 1-2-3 program written at U.S. EPA-Air and Energy Engineering Research Laboratory (AEERL).

E. TEST DESCRIPTION

In both test series, representative workpieces were prepared and coated according to normal operating procedures. During each such painting run, measurements were made of one of the four pollutant classes using the methods specified in Section D. A typical painting session lasted 30 to 90 minutes, and included postpainting cleaning of the paint spray gun with methyl ethyl ketone (MEK) and tidying up of the area. In general, two sets of tests were accomplished during an 8-hour shift, corresponding to a typical workday. A complete series of blood chemistry parameters was determined for the painter at the conclusion of the testing.

F. RESULTS

Concentrations of airborne toxic pollutants are recorded in the tables of the report. Strontium chromate occurs as the major contaminant during primer coating and was the largest contributing factor to the E_m. Organic exposures were minor during all painting exercises, except that high isocyanate exposure occurred outside, but not inside, the painter's respirator during topcoat application inside a comfort pallet (caused by airflow restrictions in the closed space, and unrelated to the mode of ventilation in the booth). The newly constructed recirculation duct was a source of several metals. These metals were included in E_m calculations, but the concentrations are expected to decrease after the newly constructed surfaces are blown clean. Contributions to E_m from recirculation are significantly less than the Air Force criterion of 0.25 imposed by HQ AFLC/SGBE for these tests, and much less, in

general, than the contribution from the painting process. The painter showed no evidence of overexposure during the posttest medical evaluation.

G. CONCLUSIONS

Data support the prediction that workplace exposure levels during recirculation of paint spray booth exhausts, especially combined with split-flow extraction of the pollutant-enriched lower portion of the exhaust stream, can be maintained less than an arbitrarily selected criterion (here, E_m = 0.25). Flow splitting as a technology is only marginally effective; however, in combination with recirculation, it acts to lower the concentrations in the recirculated stream at a given rate of recirculation. Computational projection of E_m to larger recirculation rates, and interpolation of results of an earlier economic analysis of scale-related costs to decontaminate exhaust air, indicate that available cost savings allow projected payback periods on the order of 1 year for thermal or catalytic incineration.

H. RECOMMENDATIONS

Improvements should be examined to augment or replace present-generation filter and water particulate control systems. Concurrently, or when the improved technologies satisfy local standards, a combination of flow reduction and VOC control should be implemented in an area of intense regulatory pressure as the definitive prototype. A standardized set of criteria should be established to guide site selection, design, installation, and maintenance.

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PREFACE

This final report was prepared by Acurex Environmental Corporation, 555 Clyde Avenue, Mountain View, CA 94043, under Contract No. 68-D2-0063, for the U.S. Environmental Protection Agency (EPA), Air and Energy Engineering Research Laboratory (AEERL), and the Armstrong Laboratory Environics Directorate (AL/EQ), 139 Barnes Drive, Tyndall Air Force Base (AFB) FL 32403-5323. The industrial hygiene evaluation was performed by Clayton Environmental Consultants, 1252 Quarry Lake, Pleasanton, CA 94566.

This report describes measurements of background concentrations of airborne toxic pollutants in Booth 2, Building 845, Travis AFB, CA; design and construction of modifications to the booth ventilation system; measurements of airborne toxic pollutants in the modified booth during split-flow and concurrent split-flow and recirculating ventilation; and a projective analysis of equivalent personnel exposures and net costs to operate flow reduction and emission control systems at varying recirculation ratios. The work was performed between February 1991 and September 1992. The Air Force project officer was Dr. Joseph D. Wander. EPA project managers were Charles H. Darvin and Jamie K. Whitfield.

Indispensable cooperation and support were provided by a number of Air Force functions. Ted Liston (60 EMS/MAEFP) provided facilities in Building 845 and practical advice; Terry Kirkbride (60 EMS/MAEFP) and Mark Sandy (60 ABG/EM) managed coordination with cognizant Travis functions and solicited volunteer painters; Sgt. Bill Fleming and Bill Harrison painted during the baseline and split-flow tests, respectively; Richard Smith painted during the recirculating ventilation tests; TSgt. Haugen (DGMC/SGPM) saw to the posttest evaluation of Mr. Smith and secured his release of the test results; Det 6 AL/SAO, Brooks AFB TX, performed metals and isocyanate analyses; Major John Seibert, Det 6 AL/EHI and the designee of Col. Bruce Poitrast, AL/OE-CA, was an active contributor to discussions of baseline data and the test plan for the recirculation tests; Col. Phil Brown, HQ AFLC/SGBE, accepted responsibility for authorizing the performance of the recirculation tests, after several iterative discussions of these baseline results plus data and conclusions from experimental verification of the capability of flame ionization detector (FID) technology to reliably detect equivalent exposure limit of a complex (specified) mixture of paint solvents. Major Steve Bakalyar, AL/OEMI, offered constructive suggestions and contributed to the final version of this document.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

a	Fraction of pollutants found below the split height
A	Area
ACGIH	American Conference of Governmental Industrial Hygienists
AEERL	U.S. EPA Air and Energy Engineering Research Laboratory
AFB	Air Force Base
APCD	Air Pollution Control District
ASA	Analysis safety alarm
ASE	Analysis safety element
AST	Analysis safety transmitter
ASV	Analysis safety valve
BAAQMD	Bay Area Air Quality Management District
BACT	Best Available Control Technology
Btu	British thermal unit
C	Booth concentration
CEM	Continuous emissions monitoring
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
DI	Deionized (water)
DQO	Data quality objective
dscfm	Dry standard cubic feet per minute
EM	Environmental Management
E_m	Equivalent exposure for a mixture of air contaminants, scaled in multiples of the permissible 8-hour time-weighted average
EPA	U.S. Environmental Protection Agency
FID	Flame ionization detector
fpm	Feet per minute
HDI	Hexamethylene diisocyanate
kg	Kilograms
MACT	Maximum Achievable Control Technology
MDI	Methylene diphenyl diisocyanate
MEK	Methyl ethyl ketone
MIBK	Methyl isobutyl ketone

MSDS	Material Safety Data Sheet
NA	Not applicable
N.A.	Not available
(NA)	Not analyzed
ND	Not detected
NM	Not measured
NFPA	National Fire Protection Agency
NIOSH	National Institute of Occupational Safety and Health
OAQPS	U.S. EPA Office of Air Quality Planning and Standards
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PF	Protection factor for respiratory equipment
PGMEA	Propylene glycol monoethyl ether acetate
ppmv	Parts per million volume
Q	Flow rate
QA	Quality assurance
QC	Quality control
QEC	Quick engine change
R	Recirculation ratio
RACT	Reasonably Available Control Technology
RPD	Relative present difference
RTI	Research Triangle Institute
scf	Standard cubic feet
scfm	Standard dry cubic feet per minute
STEL	Short-term exposure limit
TDI	Toluene-2,4-diisocyanate
TLV	Threshold limit value
TOC	Total organic carbon
TUHC	Total unburned hydrocarbon
v	Velocity
VOC	Volatile organic compound
Subscript	
b	Bottom section of exhaust plenum
fresh	Fresh air stream

i	Component ***i***
in	Intake
intake	Intake stream
recirc	Recirculated air stream
t	Top section of exhaust plenum
unmod	Unmodified, single pass flow conditions

METRIC CONVERSION TABLE.

English	SI	SI Symbol	To Convert from English to SI, Multiply By
Area			
Square inch	Square centimeter	cm^2	6.452
Square foot	Square meter	m^2	0.09290
Length			
Inch	Centimeter	cm	2.54
Foot	Meter	m	0.3048
Volume			
Cubic inch	Cubic centimeter	cm^3	16.387
Cubic foot	Cubic meter	m^3	0.02832
Mass			
Pound mass	Kilogram	kg	0.4536
Work, Energy, Heat			
Btu	Joule	J	1055
Btu	Kilowatt-hour	kWh	0.000293
Kilowatt-hour	Kilojoule	kJ	3600
Power, Heat Rate			
Horsepower	Watt	W	745.7
Btu/hour	Watt	W	0.2931
Temperature			
Fahrenheit	Celsius	°C	5/9(°F-32)
Flow Rate			
Cubic foot/minute	Cubic meter/second	m^3/s	0.0004719

SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this program was to demonstrate that split-flow and recirculating ventilation, individually and in combination, are safe and cost-effective methods to reduce paint spray booth exhaust flow rates and to lower the costs both of conditioning intake air and of controlling volatile organic compound (VOC) emissions in exhaust air.

B. BACKGROUND

The U.S. Air Force, in a joint effort with the U.S. Environmental Protection Agency (EPA), is conducting an extensive research program to develop cost-effective methods of controlling VOC emissions from Air Force spray painting operations. This study was part of an extended program of investigations into the cost and efficacy of innovative approaches for bringing Air Force industrial operations into compliance with current and anticipated air pollution environmental standards. The specific operation of interest in this study was aircraft-related equipment painting, in which solvent-based epoxy primers and solvent-based polyurethane topcoats are used. Some of these Air Force coatings, although approved for corrosion control, exceed the current established limits for VOC content. These limits were established by the EPA, and by state and local regulatory agencies, to achieve compliance with the Clean Air Act.

Adequate ventilation of paint spray booths requires movement of large quantities of air, which are slightly contaminated during passage through the booth. Air exhausted from this process requires decontamination, which, although technically achievable at operating flow rates, can be prohibitively expensive. Because emission-control costs depend on the volume of air being treated, considerable savings can be realized by applying an acceptable flow-reduction method.

Results from previous EPA and Air Force joint studies indicate that airborne toxic pollutants concentrate in the lower regions of cross-flow paint spray booths. This finding led to the development of three cost-saving strategies for paint spray booth ventilation: split-flow ventilation, recirculating ventilation, and combined split-flow/recirculating ventilation.

C. SCOPE

Two flow-reduction strategies were tested in this project: split-flow ventilation and combined split-flow/recirculating ventilation. Test data were used to project the impact of different recirculation ratios, both with and without split-flow ventilation. The flow-reduction strategies were evaluated based on worker safety and economic criteria. The project also experimentally evaluated the feasibility of using an automated ventilation control system that continuously monitors VOC concentrations in the recirculated airstream (as required by National Fire Protection Agency [NFPA] codes) to ensure against inadvertent overexposure of personnel working in the booth.

D. APPROACH

To achieve the project objective, two test series were conducted: baseline, and combined split-flow/recirculating ventilation. The baseline test series characterized the distribution of toxic pollutants at the exhaust face and in the exhaust duct of Booth 2. These results were used to locate the split position and the recirculation rate for the split-flow/recirculating ventilation test series. These data and the test plan for the second set of tests were reviewed by HQ AFLC/SGBE before approval was given to proceed with the recirculation tests.

Prior to the second test series, the ductwork in Booth 2 was reconfigured to separate exhaust streams from the top and bottom of the booth (split-flow) and to return the upper exhaust stream to the intake plenum for recirculation through the booth. The split-flow/recirculating ventilation test series demonstrated the feasibility of flow reduction to enhance the economics of VOC emission control. During this test series, several split-flow tests were also conducted to verify that split-flow ventilation by itself improves the economics of VOC emission control, and that the ventilation system was designed correctly. The results of the split-flow/recirculating ventilation and split-flow tests were also used to evaluate the impact of recirculation on pollutant concentration profiles in the booth.

For the baseline and split-flow/recirculating ventilation test series, comprehensive sampling and analysis matrices were developed. Each test matrix included sampling in the ventilation ducts and in the booth at the exhaust face to measure concentrations of VOCs, particulate, metals, and isocyanates. In-booth sampling identified constituent concentration profiles at the exhaust face during painting as well as concentrations in the vicinity of the painter. Duct sampling yielded constituent concentrations in the ventilation streams. Such engineering parameters as temperature, pressure, and flow rates were also measured.

The purpose of the test program was to determine the effectiveness of the split-flow and recirculation modifications in typical Air Force painting operations; it was a proof-of-concept study only. It is recognized that the concentration gradients that occur during painting depend on both the flow parameters of the ventilation system, and the size and orientation of the object painted. In general, small workpieces (less than 5 feet high) are painted at the Air Force facility targeted for conversion. Previous studies have demonstrated that, under these conditions, favorable concentration gradients occur.

Each activity conducted at Travis AFB depended upon approval prior to the start of the activity. Details of proposed activities were sent to Travis AFB and the base Environmental Management (EM) Office, to expedite approval by the respective fire, safety, and bioenvironmental engineering authorities before commencement of booth testing or modification activities. In addition, the test plan was reviewed and approved by HQ AFLC/SGBE.

SECTION II

ISSUES, PAST STUDIES, DISCUSSION OF OPTIONS

This section describes the issues, past studies, and available options pertaining to flow-reduction strategies.

A. ISSUES

Worker safety and air pollution control issues are discussed below as they pertain to flow reduction strategies.

1. Worker Safety

Until recently, the Occupational Safety and Health Administration (OSHA) prohibited the use of recirculation as a means of lowering VOC emission control costs associated with paint spray booths.

The OSHA regulation 29 CFR (Code of Federal Regulations) 1910.107 (d) (9) (Reference 1) states the following:

> Air exhaust from spray operations shall not be directed so that it will contaminate makeup air being introduced into the spraying area or other ventilating intakes, nor directed so as to create a nuisance. Air exhausted from spray operations shall not be recirculated.

This regulation was developed from NFPA Code 33-1969, which is explicitly a fire and explosion safety standard. Subsequent amendments to NFPA Code 1969, adopted in 1985, permit recirculation with adequate monitoring and warning systems installed in the booth.

In December 1989, after consultations with the EPA-AEERL and Office of Air Quality Planning and Standards (OAQPS), OSHA issued a ruling that recirculation may be used in paint booths as long as the air quality in the booth complies, at a minimum, with the requirements identified in 29 CFR 1910.1000, which establishes permissible exposure limits (PELs). A copy of the letter affirming this allowance is provided in Appendix A. Successful industrial applications have also been accomplished; an example of a permanent variance is reproduced in Appendix B. An example of OSHA's treatment of recirculating facilities is reproduced in Appendix C, a citation for unrelated violations in a recirculating facility.

The PELs are listed in 29 CFR 1910.1000 for various compounds (Reference 1). In addition, it also presents the following equation for calculating the equivalent PEL for a mixture of air contaminants exhibiting a common mode of toxicity:

$$E_m = \sum\left(\frac{C_i}{L_i}\right) \qquad (1)$$

where:

E_m = The equivalent exposure for the mixture
C_i = The concentration of contaminant i
L_i = The PEL for substance i as specified in Subpart Z of 29 CFR Part 1910

An E_m value greater than unity (1.0) implies that the toxicity level exceeds the exposure limit during an 8-hour work shift of a 40-hour workweek. An E_m less than unity implies that the equivalent exposure for the air mixture is within acceptable worker exposure limits.

2. Pollution Control Requirements

The Clean Air Act Amendments of 1990 will have a substantial impact on aerospace coating facilities. In particular, Title III of the 1990 Amendments establishes a list of 189 federally-regulated hazardous air pollutants (HAPs). The Amendments direct the EPA to promulgate emissions standards for each category of major and area sources of HAPs; the emission standards for surface coatings in the aerospace industry are due by November 15, 1994. Compliance dates for existing sources will be within 3 years of each standard's effective date (Section 112(i)(3)(B)). Section 112(d) requires these standards, referred to as Maximum Achievable Control Technology (MACT), to achieve the maximum degree of reduction in HAP emissions. MACT standards must take into account the cost of emissions reductions, non-air quality health and environmental impacts, and energy requirements. For existing sources, the MACT emission standards must be at least as stringent as the average emissions limitation of the best 12 percent of existing sources (Section 112(a)(10)).

Currently, thermal and catalytic incineration and adsorption are three commonly used controls in surface coating operations. If these or any other types of add-on control device are required by the MACT standards, the capital and operating costs will be significant given the large flow rates used in aerospace coating facilities. These costs can be significantly decreased through the use of flow reduction strategies, which decrease the flow rate through the control device, thereby decreasing the control device size (see Section VII). Thus, EPA MACT requirements may, in effect, result in the implementation of recirculating ventilation in paintbooths as an economically feasible option to obtain compliance.

B. PREVIOUS RESEARCH

Emissions from paint spray booths at several Air Force test sites will not comply with future regional air pollution control district (APCD) regulations unless the emission levels are lowered. Installing a VOC emission control device downstream of a booth exhaust is a technically effective method of achieving a high degree of VOC emission control. However, the associated capital, installation, and operating costs can be high, because the control device must be sized sufficiently large to process the large volumetric air flow and the low solvent concentrations associated with paint spray booth emissions (Reference 2).

Recent studies by the EPA and Air Force indicate that the cost of VOC emission control is significantly decreased by reducing the paint spray booth exhaust flow rate to a downstream emission control device. A 1988 study suggested that recirculation of paint spray booth exhaust, accompanied by a VOC control device, is an effective flow-enhancement method of achieving cost-effective VOC emission control (Reference 3). This method of flow reduction is referred to as recirculating ventilation.

To implement this flow-reduction concept, it must first be established that recirculation does not cause an accumulation of toxic compounds in the booth (which would create unsafe working conditions). To confirm this contention, the spatial distribution of VOC, particulate, metal, and isocyanate species was measured during typical operations in a working paint spray booth at Hill AFB, Utah (Reference 4). The study found that low concentrations occur throughout most of the booth during normal operation, except that the toxic compounds tended to concentrate toward the lower regions of the booth and immediately in front of the painter. A flow-reduction ventilation system taking advantage of this phenomenon was designed, in which the plenum chamber located behind the exhaust face is modified to accommodate two exhaust ducts. This is referred to as split-flow ventilation (Reference 5).

C. FLOW-REDUCTION TECHNIQUES

Three flow-reduction techniques are described in the subsections that follow: split-flow ventilation, recirculating ventilation, and combined split-flow/recirculating ventilation.

1. Split-flow Ventilation

A split-flow ventilation system (patent pending) (Reference 5) takes advantage of the constituent concentration gradients that naturally occur in most painting operations. A split-flow duct segregates the exhaust plenum into two streams: the air stream with the larger solvent concentration, which is exhausted to a VOC emission control device, and the second air stream, which is vented through a second plenum section to the outside.

Figure 1 is a schematic diagram illustrating the split-flow ventilation concept. The concentration gradient is determined by height and direction of paint application. If the concentration in the top portion is sufficiently low, the air stream from the upper zone may be discharged without treatment. As shown in the figure, 75 percent of the pollutants released are contained within the bottom half of the exhaust plenum, and the remaining 25 percent in the top half. In such a case, the VOC mass exhausted to a VOC emission control system is indicated by the shaded portion of the figure.

The advantage of this system is that the flow rate to the VOC emission control device is reduced, and, accordingly, the size of the control device can be reduced, resulting in a reduction in control system capital and operating costs. The reduction in flow rate is directly related to the ratio of the height of the split position to the total booth height. The primary limitation of the split-flow system is that 100-percent emission control is not achievable.

To determine the concentration of pollutants in the upper exhaust plenum, a mass balance for the booth can be developed. Assuming that steady-state and well-mixed conditions prevail inside the booth, and that the fresh intake air is pollutant-free, the mass balance for split-flow ventilation will be as follows:

generation rate = exhaust rate

$$C_{unmod}Q = C_bQ_b + C_tQ_t \tag{2}$$

where:

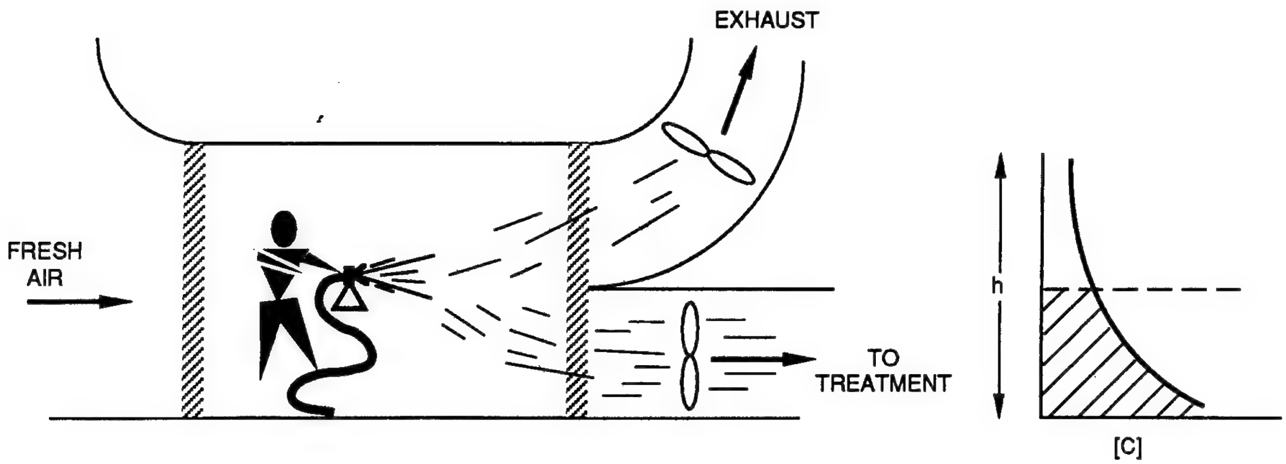


Figure 1. Schematic Diagram of a Split-Flow Ventilation System.

C_{unmod} = Concentration in unmodified booth
Q = Total booth flow rate
C_b = Concentration in bottom section of exhaust plenum
Q_b = Flow rate out bottom section of exhaust plenum
C_t = Concentration in top section of exhaust plenum
Q_t = Flow rate out top section of exhaust plenum

Defining a as the fraction of pollutants that are found below the split height,

$$a = \frac{Q_b C_b}{C_{unmod} Q} \tag{3}$$

and solving for the concentration exhausted out the top portion of the plenum,

$$C_t = \frac{C_{unmod} Q\,(1 - a)}{Q_t} \tag{4}$$

2. Recirculating Ventilation

A simple way to reduce the process flow rate to a VOC emission control device is to install a return air flow system, which recirculates filtered exhaust air back into the booth. Figure 2 is a schematic diagram illustrating a typical recirculating ventilation system. A recirculating ventilation system removes a portion of the booth exhaust through a bleed-off duct and vents to an emission control device. The remainder of the exhaust passes back into the booth through a recirculation duct installed on the exhaust plenum. Prior to reentering the paint

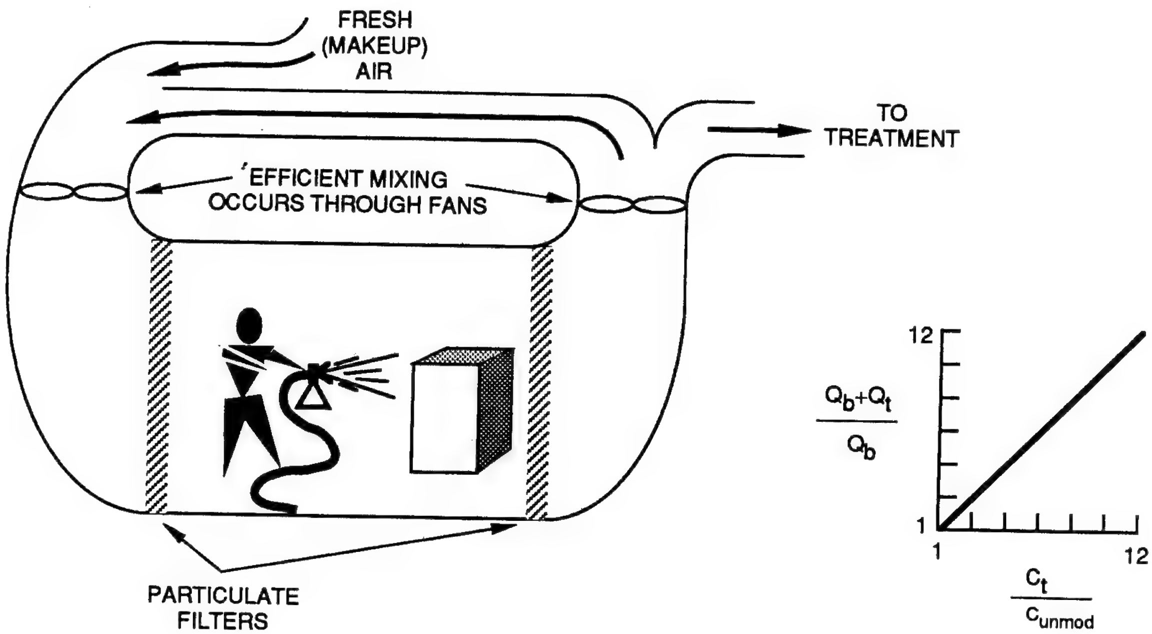


Figure 2. Schematic Diagram of a Paint Spray Booth Recirculating Ventilation System.

spray booth, the recirculated air is mixed with fresh air (brought in to replace the bleed-off air) in an intake plenum.

The advantage of the recirculation system is that it significantly reduces the exhaust flow volume, yet achieves the maximum level of VOC emission control. This decrease in exhaust flow rate reduces the capital and operating costs of a VOC emission control system because the control device capacity is determined by the bleed-off flow rate.

The Hill AFB study found that the concentrations in the vicinity of the painter are greater than the overall booth concentrations. This is due to localized perturbations in the airflow and paint gun overspray patterns, not to booth ventilation patterns. As discussed in Section VI, the increase in pollutant concentrations in the vicinity of the painter, from recirculation, is negligible in comparison to the job-intrinsic exposures.

A mass balance can be performed to determine the concentrations in the upper plenum that are recirculated into the booth. To develop the mass balance analysis for recirculating ventilation, steady-state, well-mixed flow conditions ($C_t = C_b$) are assumed. As for the split-flow mass balance, the mass generated equals the mass exhausted from the booth:

$$C_{unmod}Q = C_bQ_b \tag{5}$$

where C_{unmod} is the concentration in the unmodified booth (therefore $C_{unmod} \neq C_b$). Because,

$$Q = (Q_b + Q_t) \tag{6}$$

substitution yields

$$C_{unmod}(Q_b + Q_t) = C_b Q_b \tag{7}$$

Defining $\boldsymbol{R}$, the recirculation ratio, as

$$R = \frac{Q_t}{(Q_t + Q_b)} \tag{8}$$

then,

$$C_t = \frac{C_{unmod}}{(1 - R)} \tag{9}$$

This relationship is plotted in the graph accompanying Figure 2.

3. Combined Split-flow/Recirculating Ventilation

Significant benefits are derived from a flow-reduction system combining the recirculation and split-flow strategies, in which the split-flow exhaust air containing low constituent concentrations is recirculated back into the booth after mixing with fresh make-up air. The combined system achieves the maximum attainable control of VOC emissions, and decreases the constituent concentration in the recirculation stream to the lowest possible level for safe recirculation.

Figure 3 is a schematic diagram illustrating a combined split-flow/recirculating ventilation system. The circle "A" in the figure represents a VOC concentration monitor installed to ensure the painter's safety. The paint overspray pattern and target configuration determine the concentration in the recirculation stream.

A mass balance is performed to calculate the concentration recirculated into the booth intake from the upper exhaust plenum. For steady-state conditions, the mass balance for combined split-flow/recirculating ventilation is as follows:

$$C_{unmod}Q = C_{unmod}(Q_b + Q_t) = C_b Q_b \tag{10}$$

Furthermore,

$$\frac{a}{(1 - a)} = \frac{C_b Q_b}{Q_t C_t} \tag{11}$$

Substitution gives

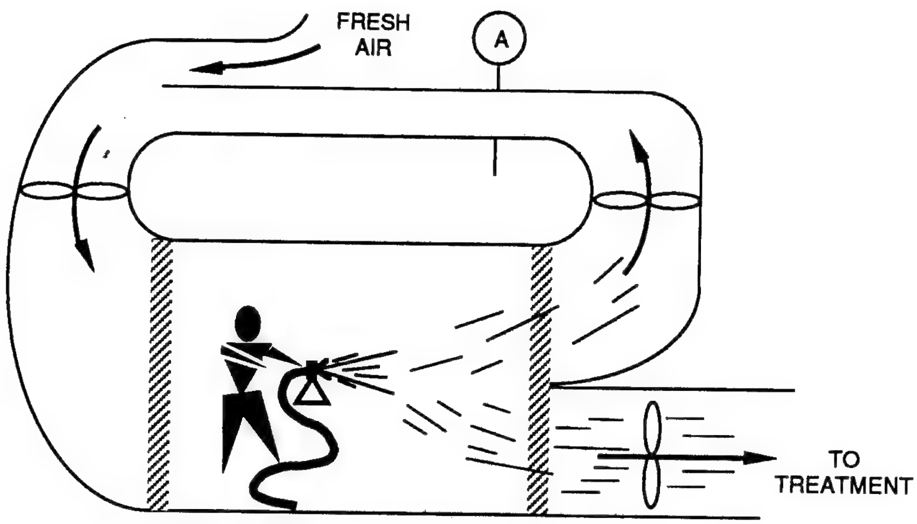


Figure 3. Schematic Diagram of a Paint Spray Booth Ventilation System Combining Split-Flow and Recirculating Ventilation.

$$C_{unmod}(Q_b + Q_t) = \frac{Q_t C_t a}{(1 - a)} \tag{12}$$

and using the definition of R, and solving for C_t gives

$$C_t = \frac{C_{unmod}(1 - a)}{(Ra)} \tag{13}$$

SECTION III

SITE DESCRIPTION AND MODIFICATION

A. SITE DESCRIPTION

Paint Spray Booth 2, Building 845, Travis Air Force Base, California, was the site selected for this airflow modification study. The interior of the booth is 25.75 feet long, 18 feet wide, and 14 feet high. It has a crossdraft ventilation system in which fresh air is introduced into the booth through a fiberglass mesh filter system at the side wall front edges. The air exits the rear of the booth through a pleated-paper/fiberglass mesh filter that completely covers the exhaust plenum. Prior to Booth 2's modification, its entire exhaust was vented to the atmosphere through a 48-inch-diameter duct located on top of the exhaust plenum. The booth is maintained under negative pressure to prevent solvent emissions into the surrounding work areas of Building 845. Figure 4 is a schematic diagram of the booth prior to modification.

The booth operators used conventional, high-pressure, high-volume paint spray guns. The flow rate in the booth was typically maintained at 30,000 cfm, for a face velocity of 120 fpm.

B. SITE MODIFICATION

As discussed in Section I, two flow-reduction strategies were tested. The booth was modified to permit both split-flow and combined split-flow/recirculating ventilation. The flow-reduction design incorporated most of the existing equipment, including fans and ductwork. Because the booth operated on a light schedule, booth downtime during modification did not affect Air Force operations. The total modification time was less than 1 month. The design package for the booth modification is presented in Volume II, Appendix D.

The modification accommodated split-flow ventilation and combined split-flow/recirculating ventilation. For the test program, a physical division was established between the upper and lower plenums to maintain a known, consistent stream-split height. Prior to modification, the baseline test series was conducted. Based on the results (Section IV), the split-height of 7.5 feet was selected to produce an approximate exhausted/recirculated flow-volume split of 54/46. A sheet metal transition piece, 7.5 feet high and as wide as the booth, was installed on the floor of the existing plenum and set tight against the back of the exhaust filter media. This transition piece was connected to the new exhaust duct and exhaust blower. The creation of a new enclosed plenum required the installation of a fire suppression system with associated piping, electrical, and alarm connections. The upper chamber vented to the existing atmospheric exhaust duct.

In this test, a physical barrier was used to separate the exhaust and recirculated streams to ensure absolute certainty about the split-stream height and the relative flow volumes. However, a split-stream configuration could have been achieved without a physical division between the upper and lower plenums. By providing a blower with a lower duct located at or near the floor of the existing plenum, and a second blower at the upper duct (recirculating or exhausting air to atmosphere), the existing exhaust flow could be separated. The ratio of air exhausted to the upper and lower regions would be proportional to the force of the two blowers. In this case, the pollutant-rich stream, normally concentrated in the lower half of the paint booth, would remain in the lower half as it exited the booth through the exhaust duct located near the

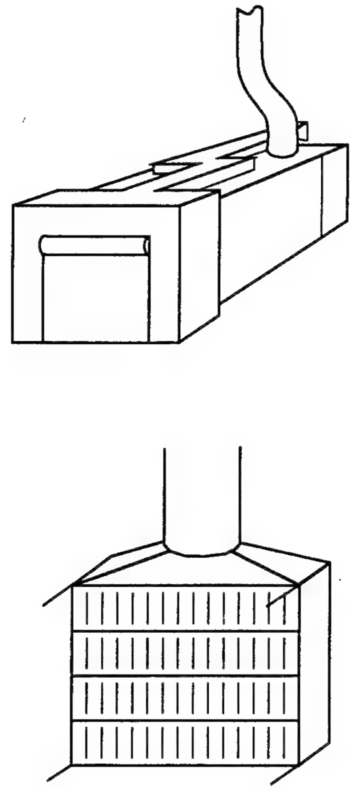


Figure 4. Schematic Diagram of Original Paint Spray Booth 2 Configuration.

floor. The duct towards the roof of the plenum would collect the remaining, relatively clean exhaust stream.

In the combined split-flow/recirculating ventilation configuration of the paint booth, the lower duct vented the pollutant-rich stream to the outside. The stream with lower solvent concentrations passed through the rerouted upper-chamber exhaust duct. This upper duct, modified with new ducting and two dampers, passed from the upper exhaust plenum chamber over the paint booth roof to the existing intake plenum. In this plenum, the recirculated air was mixed with fresh air, which was brought in to replace the air bled off by the new exhaust blower. An intake fan drew this mixed air into the intake plenum and through the intake filters into the booth.

The system design modifications were developed based on the baseline test series results. No modification to the intake face was required because a sealed intake plenum already existed. Figure 5 is a schematic diagram of the booth after modification.

C. SAFETY PRECAUTIONS

Special safety procedures were followed to prevent accidental overexposure of personnel in the booth. During painting operations, the painter wore a positive-pressure airline respirator and a fully enclosed suit. Therefore, a transient increase in pollutant concentrations in the booth did not pose any increased health risk.

As an additional safety measure, the VOC concentration in the recirculated stream was continuously monitored upstream of the intake face during the combined split-flow/recirculating ventilation test series. To ensure painter safety, the monitor was attached to an automatic

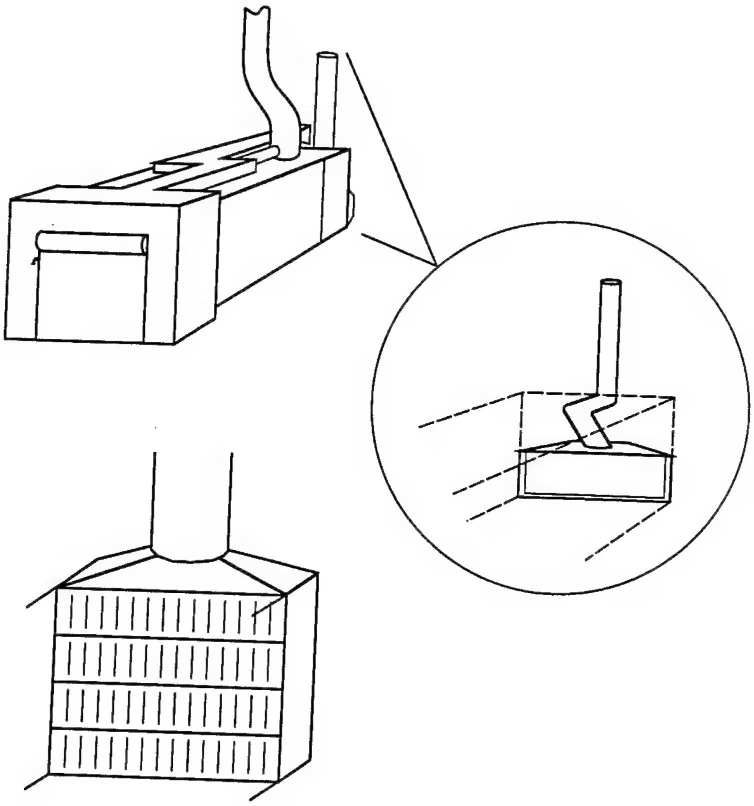


Figure 5. Schematic Diagram of Modified Paint Spray Booth 2.

control system that converted the booth to conventional single-pass operation if the measured VOC concentration exceeded predetermined concentration setpoints. Two setpoints were established: an instantaneous concentration setpoint, and a 60-second average concentration setpoint. The instantaneous setpoint was defined as 350 ppm, the calculated short-term exposure limit (STEL) for a typical paint mixture (Reference 6). The 60-second average setpoint was set at 320 ppm. The intake concentration was monitored with an FID. Research was conducted at the Research Triangle Institute (RTI) to determine the FID response for a mixture of solvents at the STEL (Reference 6). Whenever either setpoint was exceeded, the booth converted automatically to single-pass operation, quickly expelling the entire booth volume.

Conservative by common workplace standards, these exposure controls—personal respiratory equipment, safety suits, and fail-safe conversion out of recirculation configuration — minimized worker safety risks during this test series.

During recirculating ventilation tests, the inlet air heater, an open-flame model, was shut off for safety and emission monitoring reasons. If the inlet air must be heated, another type of heater should be installed, preferably an electric heater located upstream of the mixing point of the recirculation and fresh air streams. Open-flame heaters may create a fire or oxygen depletion hazard in recirculating ventilation designs.

SECTION IV

BASELINE TEST MATRIX AND RESULTS

A 1-week baseline test series was conducted during April 1991 to characterize unmodified paint spray booth operations and emissions, using Booth 2 as the test site. The objective of the test series was to obtain sufficient data to determine the vertical distribution of pollutants in the booth and determine a conservative split height for the split-flow/recirculating ventilation booth modifications. The data were also used to calculate equivalent exposure levels in the vicinity of the painter that are compared with the postmodification equivalent exposure results in Section VI to determine the practicability of flow modifications.

A. SAMPLING LOCATIONS

Figure 6 shows the sampling locations for the baseline test series. These locations included the booth exhaust face (Site B), the exhaust duct (Site C), and inside and outside the painter's airline respirator hood (Site A). At the exhaust face, data were collected at 24 sampling locations, as shown in Figure 7.

B. SAMPLING METHODS

The baseline test matrix and analytical methods used are summarized in Table 1. Four pollutant categories—particulate, organics, isocyanates, and metals—were selected for sampling, for the following reasons:

- Organic species are primary constituents of virtually all Air Force coatings.
- Particulate matter is released from spray-painting operations.
- Metals, such as strontium chromate, lead, and zinc, are found in many coatings, especially primers.
- Isocyanates are found in polyurethane topcoats.

For each pollutant category, two 1- to 1.5-hour sampling events were conducted. Eight sampling events, in total, were conducted over a 1-week period. With the exception of NIOSH Method 1300, all sampling and analytical procedures were as specified in the respective methods used. Justification for the sampling and analytical methods employed is provided in Subsections 1 through 4 that follow.

1. Organic Compound Sampling

NIOSH Method 1300 was used for organic-compound sampling. In this test series, the method was modified based on results from previous military paint spray booth testing events. Larger charcoal tubes than required by NIOSH Method 1300 were used. The use of these larger tubes consistently resulted in sufficient sample collected with minimum solvent breakthrough. The extraction solvent was modified specifically for use in desorbing solvents used in military paints from charcoal sampling tubes. The laboratory desorption study conducted in support of the solvent modification is provided in Volume II, Appendix E.

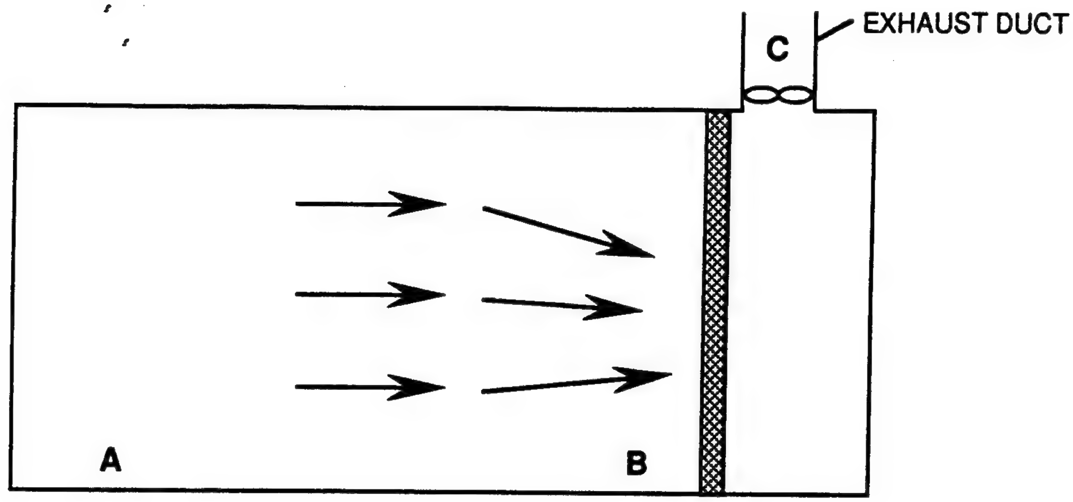


Figure 6. Sampling Locations for Baseline Test Series.

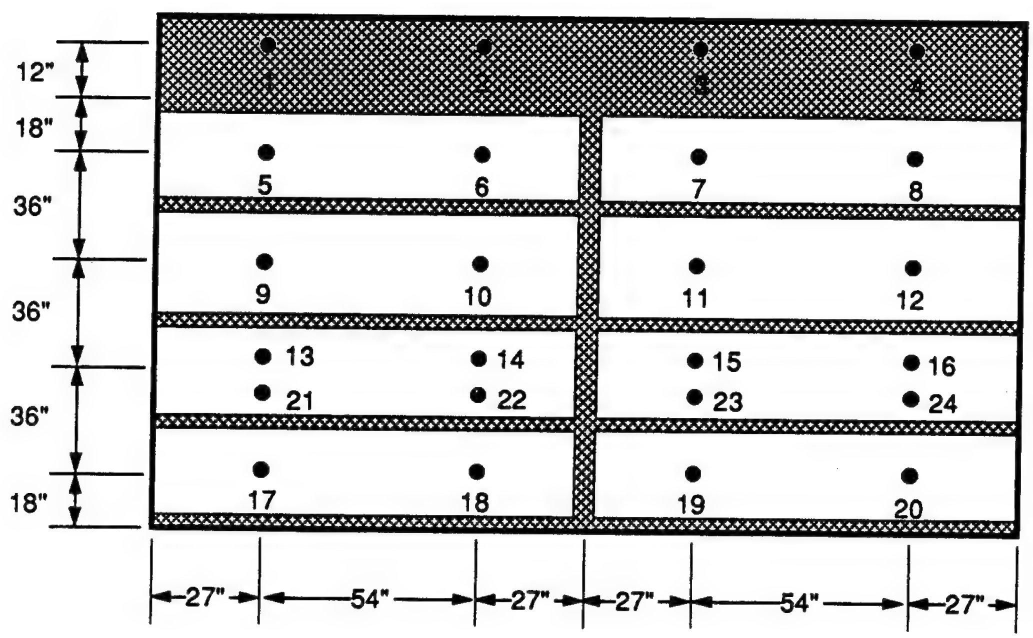


Figure 7. Sampling Locations at the Exhaust Face of Booth 2 at Travis AFB.

TABLE 1. SAMPLING MATRIX FOR BASELINE TEST SERIES.

Parameter	Sampling Location	Sampling Method	Number of Tests
Organics	Exhaust duct	NIOSH Method 1300[a] BAAQMD Method ST-7[b] EPA Method 25A	8 8 8
	Exhaust face, vicinity of painter	NIOSH Method 1300	2
Particulate	Exhaust duct	EPA Method 5[c]	6
	Exhaust face, vicinity of painter	NIOSH Method 500[a]	2
Metals	Exhaust duct	EPA Draft Multiple Metals[d]	2
	Exhaust face, vicinity of painter	NIOSH Method 7300[a]	2
Isocyanates	Exhaust duct	OSHA Method 42[e]	2
	Exhaust face, vicinity of painter	OSHA Method 42	2
Flow rate	Exhaust duct	EPA Method 2[c]	8
	Exhaust face	ACGIH[f]	8
Paint usage	Booth	Gravimetric Manual Recording	8
Paint % volatile, density	Booth	Grab	1 sample per paint

[a]Reference 7.
[b]Reference 8.
[c]Reference 9.
[d]Reference 10.
[e]Reference 11.
[f]Reference 12.

NIOSH Method 1300 specifies that pure carbon disulfide (CS_2) be used in extracting solvents from charcoal tubes. However, experience has shown that CS_2 does not completely desorb most of the solvents present in Air Force coatings, including alcohols, toluene, and cellosolves. Therefore, an appropriate extraction solvent mixture developed specifically for this application was substituted for this test series. The improved solvent mixture, consisting of 5 percent acetone in CS_2, proved successful in desorbing the various types of solvents typically found in military coatings (see Volume II, Appendix E). Following their extraction from the charcoal tubes, the extracts were analyzed, as specified in the method, via gas chromatography/flame ionization detection (GC/FID). The paint solvent compounds targeted for analysis are listed in Table 2.

TABLE 2. ORGANIC SPECIES TARGETED FOR NIOSH METHOD 1300 ANALYSIS.

bis(2-Methoxyethyl) ether	Ethoxyethanol	PGMEA[a]
Butyl acetate	MEK[b]	Toluene
Ethyl acetate	Methoxyacetone	2-Ethoxyethyl acetate
Ethylbenzene	MIBK[c]	Xylenes (total)

[a]PGMEA = Propylene glycol monomethyl ether acetate.
[b]MEK = Methyl ethyl ketone.
[c]MIBK = Methyl isobutyl ketone.

Continuous emission monitoring (CEM) was conducted in both the split-flow duct and the recirculation duct. Two CEM methods were employed: BAAQMD Method ST-7 and EPA Method 25A. Method ST-7 procedure specifies that the sample stream pass through a catalytic combustion tube, in which the organic compounds present in the stream are oxidized to CO_2. The oxidized sample stream then passes into a nondispersive infrared (NDIR) detector, which continuously monitors the CO_2 concentration. The combustion tube is periodically bypassed to monitor the background CO_2 concentration. The total organic carbon (TOC) measurement is determined as the difference between the CO_2 concentrations measured in the sample and bypass streams. The method is not reliable when background CO_2 constitutes more than 85 percent, on a molar basis, of the total carbon in the sample. The method also specifies that the minimum concentration of organic compounds be 10 ppm if the appropriate NDIR cell is used and that the minimum sensitivity of the NDIR is 2 percent of full scale.

EPA Method 25A uses an FID to measure the concentration of unburned hydrocarbons in the sample stream. The FID is calibrated with propane, which has a detector response factor that differs from the response factors of the paint solvents. In addition, the presence of oxygenated organics, such as alcohols or esters, causes the organic compound concentration to be underpredicted by the FID. In general, these factors and operational constraints cause Method 25A to be less quantitative than Method ST-7. However, in instances where either the sample TOC concentration is significantly less than the background CO_2 concentration or a low signal-to-noise ratio is observed during Method ST-7 testing, Method 25A provides the more reliable data.

2. Particulate Sampling

Ambient air particulate sampling was conducted using NIOSH Method 500. This method is approved by several regulatory agencies for use in determining ambient particulate concentrations in the workplace. Furthermore, it has been applied in the past to determine particulate concentrations in Air Force paint spray booths during painting operations.

The EPA Method 5 particulate sampling procedure was used in the ventilation ducts. This method is approved for source testing applications by the EPA, and has been used successfully in the past to quantify particulate emissions from military painting operations.

3. Metals Sampling

NIOSH Method 7300 and the EPA Draft Multiple Metals sampling procedure were used in the metals sampling. NIOSH Method 7300 is a reliable metals-sampling method that has

been used previously in similar paint spray booth sampling efforts (References 2 and 4). The EPA Draft Multiple Metals sampling procedure is also commonly used in source test applications.

4. Isocyanate Sampling

Several methods are available to determine airborne isocyanate concentrations, including spectrophotometric, impinger, filter, and paper tape. The dry filter method (OSHA 42) was selected because the logistical and safety issues associated with impinger methods rendered their use infeasible in this test series. In the expected concentration ranges, the dry filter system is as reliable as other integrated sampling methods (Reference 13).

C. PAINT CONSUMPTION DURING BASELINE TEST SERIES

Three types of paints were used in Booth 2 during the baseline test series: a two-part polyester resin and aliphatic resin topcoat, a two-part polyurethane and aliphatic isocyanate topcoat, and a two-part epoxy and polyamide primer. Both of the topcoats are prepared in a 1-to-1 pigment-to-catalyst volume ratio. The primer is mixed at a 2-to-1-to-1 water-to-pigment-to-catalyst volume ratio. Samples of each pigment and catalyst were collected and analyzed for density and percent volatiles. The results are presented in Table 3.

Paint usage was monitored by a sampling crew member stationed in the booth. For each sampling event, the type of paint used, the total weight of the paint used, and the size and orientation of the object painted were recorded. Paint usage data are summarized in Table 4. The data related to the type and quantity of paint used in this test series may be compared to paint usage data from the postmodification test series.

TABLE 3. RESULTS OF PAINT DENSITY AND PERCENT VOLATILE ANALYSES.

	Percent Volatile Analysis			Measured Density	
Paint Type	Initial Weight (g)	Final Weight (g)	Percent Volatile	Pigment or Epoxy (kg/L)	Catalyst or Curing Solution (kg/L)
DI Water Blank	6.0	0.1	98	(NA)[a]	(NA)
Epoxy Primer MIL-P-85582A	62.2	35.4	43	1.91	0.92
Polyurethane Green Topcoat MIL-C-85285B	9.8	7.0	29	1.20	0.98
Polyurethane Green Topcoat MIL-C-85285B, (QA duplicate)	12.7	9.2	28	1.19	0.96
Polyurethane White Topcoat MIL-C-83286B	10.0	6.4	36	1.35	0.93

[a](NA) = Not analyzed.

TABLE 4. PAINT CONSUMPTION RATES DURING BASELINE TEST SERIES.

Date and Test	Approximate Test Time (minutes)	Time	Paint/Solvent Type	Quantity (kg)	Painted Object	Comments
16 April 1991, Metals Test 1	50	1045-1057 1114-1125	Epoxy primer	1.115	Cart	Alcohol sprayed randomly during cleaning
		1550	Alcohol	NA[a]		
16 April 1991, Particulate Test 1	50	1448-1500 1505-1525 1530-1542	Polyurethane topcoat	2.686	Not recorded	MEK sprayed randomly during cleaning
		1550	MEK	NA		
17 April 1991, Metals Test 2	113	1007-1031	Epoxy primer	0.585	Stand (12 ft L x 8 ft W x 3 ft H)[b]	Object not centered in room
		1038	MEK	0.130		
		1129-1156	Polyurethane topcoat	0.844		
		1200	MEK	0.169		
17 April 1991, Particulate Test 2	85	1605-1608	Epoxy primer	0.399	Rails and misc. parts on a table (4 ft L x 3.5 ft W x 3 ft H)	Table placed 3 ft from exhaust grid
		1608	Alcohol	NA		
		1635-1700 1703-1723	Polyurethane topcoat	1.683		
		1730	MEK	0.308		
18 April 1991, Organics Test 1	57	1101-1124 1127-1140 1144-1152	Polyurethane topcoat	2.217	Rails and misc. parts on a table (4 ft L x 3.5 ft W x 3 ft H) and a cart (4 ft L x 6 ft W)	
		1155-1158	MEK	0.314		
18 April 1991, Organics Test 2	59	1717-1740 1745-1752 1754-1803 1807-1820	Polyurethane topcoat	2.025	Parts on a table (4 ft L x 3.5 ft W x 3 ft H) and a cart (4 ft L x 6 ft W)	
		1824-1826	MEK	0.292		
19 April 1991, Isocyanates Test 1	55	1126-1140	Polyurethane topcoat	0.337	2 drums on a 3-ft-H table and a hood (3 ft L x 4 ft W x 2.5 ft H)	
		1143-1144	MEK	NA		
		1147-1202 1209-1217	Polyurethane topcoat	1.711		
		1220-1221	MEK	0.237		
19 April 1991, Isocyanates Test 2	43	1518-1527	Polyurethane topcoat	0.386	2 drums on a 3-ft-H table and a hood (3 ft L x 4 ft W x 2.5 ft H)	
		1530-1532	MEK	0.167		
		1537-1547 1550-1556	Polyurethane topcoat	1.242		
		1558-1601	MEK	0.350		

[a]NA = Not applicable.
[b]L = long, W = wide, H = high.

D. AIR FLOW RATE MEASUREMENTS

Flow rate measurements were made at the exhaust face and in the exhaust duct. The face velocity at the exhaust face ranged from 110 to 150 fpm, corresponding to a volumetric flow rate of 27,700 to 37,800 cfm. Table 5 lists the exhaust duct flow rate measurement results.

E. RESULTS OF EXHAUST FACE MEASUREMENTS

The results of the exhaust face measurements are described below for the baseline test series. The raw data for the baseline test series are presented in Volume II, Appendix F. For purposes of discussing the appropriate split-position, the reduced data are presented in graphical form in this section.

Three assumptions were made in calculating the pollutant concentrations at the exhaust face:

- Each compound neither detected nor listed in the Material Safety Data Sheet (MSDS) of the topcoat or primer was assumed to not be present.
- Each compound not detected but listed in the MSDS of the topcoat or primer was assumed present at one-half the method detection limit.
- Because there are four sampling points at each exhaust face height, pollutant concentrations shown in the figures in this section are average concentrations for each height.

1. Organic Compounds

NIOSH Method 1300 was used to define average organic concentrations of individual species during the sampling period. Because the method is an integrated sampling procedure,

TABLE 5. FLOW RATES MEASURED IN THE EXHAUST DUCT DURING THE BASELINE TEST SERIES.

Date and Test	Volumetric Flow Rate (scfm)
16 April 1991, Metals Test 1	32,614
16 April 1991, Particulate Test 1	30,194
17 April 1991, Metals Test 2	30,549
17 April 1991, Particulate Test 2	30,064
18 April 1991, Organics Test 1	31,709
18 April 1991, Organics Test 2	30,008
19 April 1991, Isocyanates Test 1	31,464
19 April 1991, Isocyanates Test 2	32,165

the results of these tests were not used to draw conclusions regarding instantaneous or peak concentrations, but, rather, the long-term average concentration.

Figure 8 presents the results of organic measurements at the exhaust face of Booth 2 during organics Tests 1 and 2. The concentrations reported in Figure 8 represent the sum of all the organic species measured in the NIOSH Method 1300 speciation analyses. The highest total organics concentration measured by integrated sampling was 34 mg/m^3.

Figure 8 also shows the spatial distribution of organics at the exhaust face; the organic species tend to concentrate in the lower section of the booth. For this reason, the air stream with lower organic concentrations in the top section of the booth may be recirculated without exceeding exposure standards.

2. Particulate

Figure 9 presents the concentrations of particulate measured at the exhaust face of the booth during particulate Tests 1 and 2. The two concentration profiles differ because the paint quantities and object heights were different in each test. The results confirm the finding of previous paint spray booth test programs that the particulate concentration at the exhaust face decreases with increasing height. It is clear that particulate concentrations are very low in the top section of the booth (less than 8 mg/m^3 above 8 feet from the bottom of the booth).

The booth was equipped with two sets of particulate filters, one at the exhaust face (downstream of the exhaust face sampling locations) and one at the booth intake. Because the exhaust face measurements were obtained upstream from the exhaust face particulate filters, the results do not affect the practical use of recirculating ventilation, even for the painting of large objects.

3. Metals

The metals samples were analyzed for the presence of four metal species: strontium, chromium, lead, and zinc. Strontium chromate ($SrCrO_4$) is listed in the primer MSDS. Lead and zinc are not listed as constituents in the MSDSs and were not detected in any of the samples.

Figure 10 presents the results of strontium chromate ($SrCrO_4$) measurements at the exhaust face during metals Tests 1 and 2. Strontium chromate concentrations were based on strontium (Sr) or chromium (Cr) measurements. Because the strontium and chromium originated from the strontium chromate in the primer, their measured concentrations were converted into the equivalent strontium chromate concentration. Each data point in Figure 10 represents the more conservative of the strontium and chromium results.

Because the metals samples were collected upstream of the exhaust face particulate filter, they are not representative of recirculated concentration measurements.

4. Isocyanates

Figure 11 shows hexamethylene diisocyanate (HDI) concentrations measured at the exhaust face during isocyanate Tests 1 and 2. Methylene diphenyl diisocyanate (MDI) and toluene-2,4-diisocyanate (TDI) were not detected at the exhaust face and are not specified in the MSDSs for the paints used.

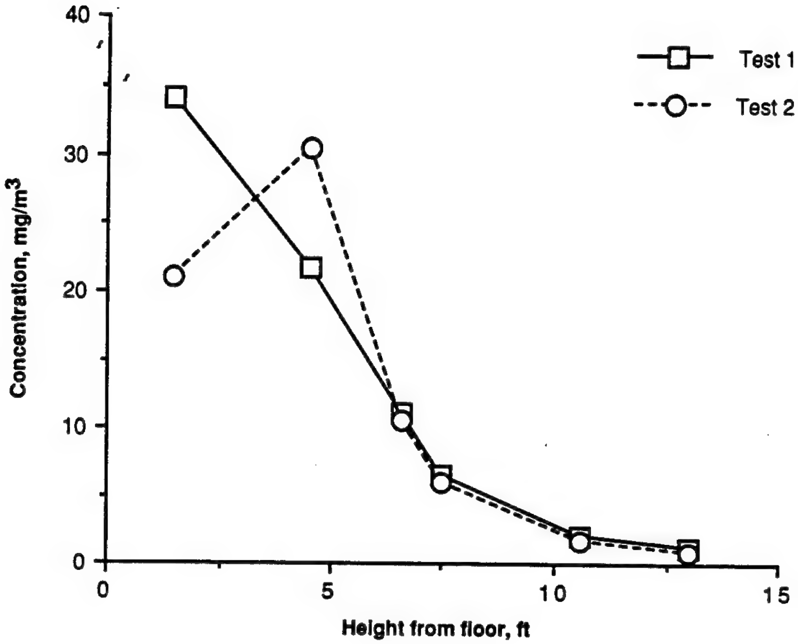


Figure 8. Results of Organic Measurements at the Exhaust Face During Baseline Testing.

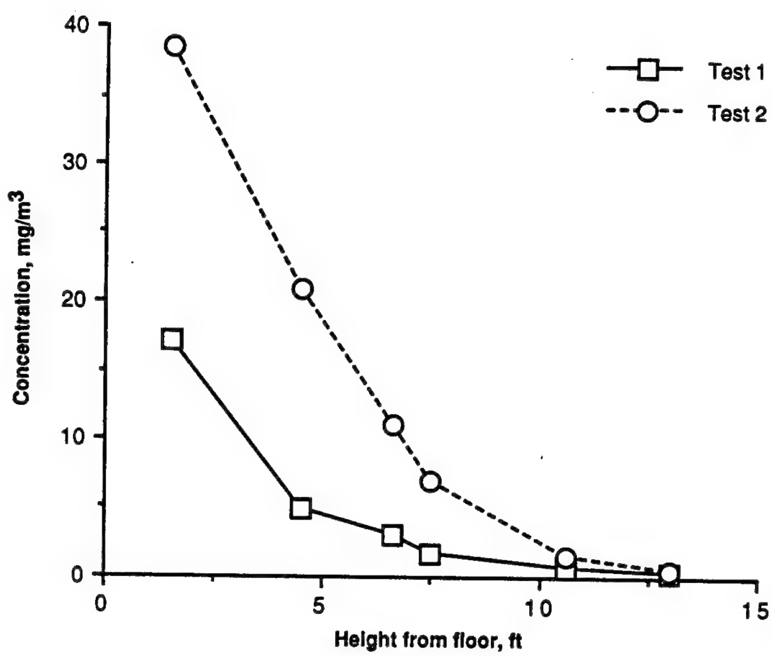


Figure 9. Measured Concentrations of Particulate at the Exhaust Face During Baseline Testing.

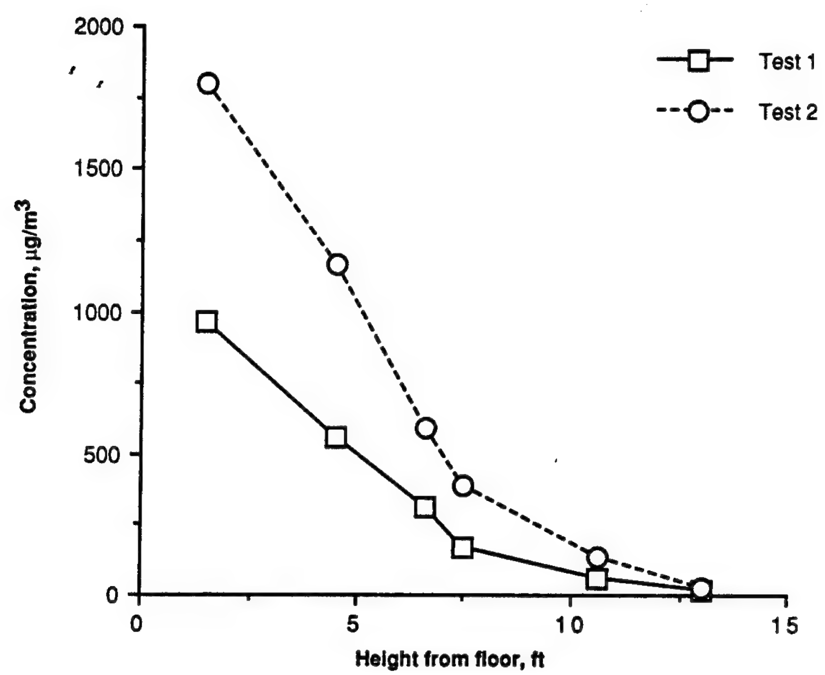


Figure 10. Concentrations of Strontium Chromate Measured at the Exhaust Face.

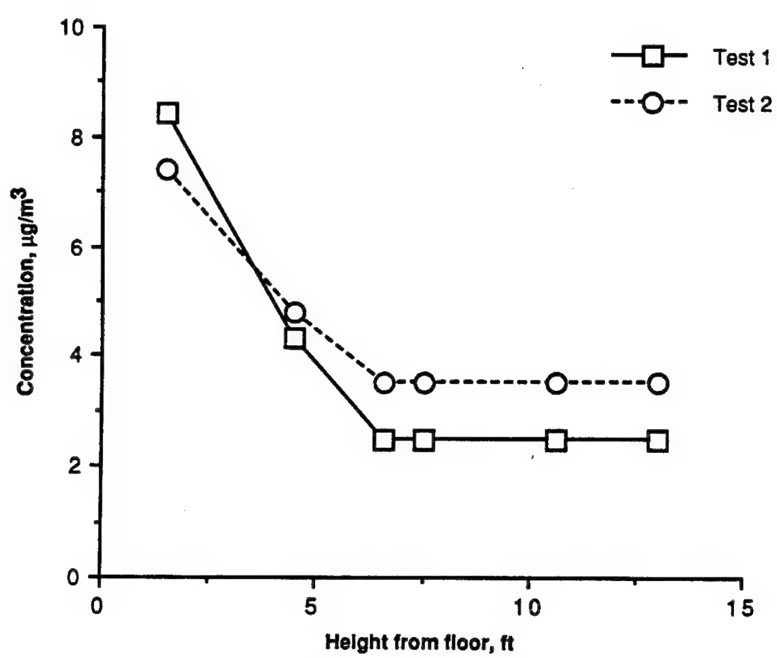


Figure 11. Baseline HDI Concentrations Measured at the Exhaust Face.

The highest HDI concentration measured at the exhaust face was 0.0085 mg/m^3. As observed for the other pollutant species, HDI concentrations decrease with increasing height. Because the samples were obtained upstream of the exhaust face particulate filter, the concentrations do not represent concentrations that would be returned to the booth intake in recirculating ventilation modes.

F. RESULTS OF EXHAUST DUCT MEASUREMENTS

The pollutant concentrations in the exhaust duct are critical parameters required to determine the pollutant concentrations in a modified paint spray booth such as Booth 2. Integrated sampling was conducted in the exhaust duct for volatile organic species, isocyanates, particulate matter, and metals. CEM for VOCs was also conducted to measure instantaneous organic concentrations during painting operations.

1. Organic Compounds

a. Integrated Sampling

Table 6 lists organic concentrations measured in the exhaust duct with NIOSH Method 1300. This method was employed during all eight sampling events. As this method is integrated, the results of these tests were not used to draw conclusions on instantaneous or peak concentrations, but rather on the long-term average concentrations.

Table 6 lists only methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), *n*-butyl acetate, and 2-butanol. The other organic species listed in Table 2 were not detected. The measured concentrations are far below the exposure limits. Hence, organic species are at safe levels upon exiting the exhaust duct.

TABLE 6. CONCENTRATIONS OF ORGANIC COMPOUNDS MEASURED IN THE EXHAUST DUCT.

Test Number	Concentration (mg/m^3)			
	MEK	MIBK	*n*-Butyl acetate	Toluene
Organics Test 1	1.4	4.2	1.1	0.64
Organics Test 2	2.8	2.9	0.63	0.34
Particulate Test 1	0.85	3.6	0.92	0.50
Particulate Test 2	<0.15[a]	0.74	<0.15	0.15
Metals Test 1	1.5	<0.26	<0.26	0.55
Metals Test 2	3.6	1.5	0.33	0.43
Isocyanates Test 1	4.4	1.9	0.51	0.25
Isocyanates Test 2	5.8	2.1	0.57	0.26

[a]< = Compound not detected. Values listed are one-half the MDL.

b. Continuous Emission Monitoring Results

CEM was conducted during all eight sampling events. Two CEM methods were employed, BAAQMD Method ST-7 and EPA Method 25A. During the baseline test series, the maximum measured total VOC concentration was 702 ppm as CO_2. Because a concentration gradient exists at the exhaust face of the booth, only a fraction of the organics measured in the exhaust duct will reenter the booth following modification of the ventilation mode to split-flow/recirculating ventilation.

2. Particulate

Table 7 lists the concentrations of particulate matter measured in the exhaust duct during the baseline test series. Because Booth 2 has particulate filters at the intake faces, the particulate measured in the exhaust duct does not represent particulate matter that would reenter the booth upon recirculation.

3. Metals

Concentrations of metal compounds (strontium, chromium, lead, and zinc) measured in the exhaust duct are listed in Table 8. The strontium and chromium both originate from the strontium chromate in the primer.

These strontium and chromium concentrations are bulk duct concentrations. In the split-flow/recirculating ventilation mode, the concentration in the recirculated stream is less than the bulk exhaust duct concentration, due to the concentration gradient phenomenon at the exhaust face. In addition, the booth is equipped with particulate filters at the booth intake. These two factors help ensure that the concentration reentering the booth in recirculating ventilation mode will be considered safe.

Because lead and zinc compounds were not detected in the exhaust duct and are not listed in the MSDSs as paint constituents, the concentrations listed in Table 8 are based on one-half the respective detection limits.

TABLE 7. CONCENTRATIONS OF PARTICULATE MATTER MEASURED IN THE EXHAUST DUCT.

Test	Particulate Concentration (mg/m^3)
Organics Test 1	2.9
Organics Test 2	2.2
Particulate Test 1	2.7
Particulate Test 2	1.7
Isocyanates Test 1	2.5
Isocyanates Test 2	1.1

TABLE 8. CONCENTRATIONS OF METAL COMPOUNDS MEASURED IN THE EXHAUST DUCT.

Test	Concentration (mg/m^3)			
	Lead	Zinc	Strontium	Chromium
Metals Test 1	<0.0087[a]	<0.0087	0.059	0.042
Metals Test 2	<0.0067	<0.0067	0.035	0.021

[a]< = Compound not detected. Values listed are one-half the MDL.

4. Isocyanates

HDI, MDI, and TDI were measured in the exhaust duct during the application of isocyanate-containing topcoat. Isocyanate compounds were not detected in the exhaust duct, and concentrations were conservatively assumed to equal one-half the method detection limits. These values are listed in Table 9 for the two isocyanate tests.

G. RESULTS OF MEASUREMENTS AT THE PAINTER

Concentrations of pollutant species measured outside and inside the painter's respirator hood are listed in Table 10. Spreadsheets containing the reduced data are presented in Volume II, Appendix F. Each compound not detected is assumed to be present at one-half the MDL.

The measured concentrations and calculated 8-hour time-weighted averages of organic and isocyanate species near the painter were all below the PEL values. No particulate was detected inside the painter's respirator.

The chromium results indicate that the measured concentrations were on the order of the PEL and ACGIH TLV in effect during 1991 (0.05 mg/m^3). However, because PELs and TLVs are based on average exposure over an 8-hour workday, the measured concentrations do not exceed OSHA or ACGIH standards. For instance, during metals Test 1, the chromium concentration measured under the painter's hood exceeded the PEL value, presumably due to leakage of booth air through the gap between the painter's hood and suit. Because the test lasted about 1 hour, and because chromium-containing paints were not used in the subsequent tests that day, this amounted to an average overall strontium chromate exposure (as chromium) of 0.0079 mg/m^3 (0.063 mg/m^3 for 1 hour, and 0 mg/m^3 for the remaining 7 hours of the workday), less than the permissible 8-hour exposure limit in effect during 1991-92.

H. RECIRCULATION AND SPLIT-FLOW CALCULATIONS

Results from sampling in the exhaust duct and at the exhaust face were used to predict the concentrations of air pollutants that would result during split-flow/recirculating ventilation. The calculations overestimate particulate-carried pollutants, such as metals and isocyanates, because the removal of particulate matter by intake filters is neglected. This section describes the distribution of pollutants at the exhaust face, and the procedure for selecting the split height and percent recirculation for subsequent split-flow/recirculating ventilation tests.

TABLE 9. CONCENTRATIONS OF ISOCYANATE COMPOUNDS MEASURED IN THE EXHAUST DUCT.

Test	Concentration (mg/m^3)		
	HDI	MDI	TDI
Isocyanates Test 1	<0.0029[a]	<0.0039	<0.0029
Isocyanates Test 2	<0.0038	<0.0038	<0.0038

[a]< = Compound not detected. Values listed are one-half the MDL.

TABLE 10. CONCENTRATIONS OF AIR POLLUTANTS OUTSIDE AND INSIDE THE PAINTER'S RESPIRATOR HOOD.

Test	Compound	Concentration (mg/m^3)	
		Outside Respirator Hood	Inside Respirator Hood
Organics Test 1	MEK	17	<0.12[a]
	MIBK	29	<0.12
	Toluene	4.0	<0.050
	n-Butyl acetate	7.7	<0.12
	Xylenes	0.26	<0.050
Organics Test 2	MEK	51	0.29
	MIBK	12	<0.10
	Toluene	1.3	<0.039
	n-Butyl acetate	2.6	<0.10
	Xylenes	0.09	<0.035
Particulate Test 1	Particulate	N.A.[c]	0.0
Particulate Test 2	Particulate	0.0037	0.0
Metals Test 1	Chromium	0.176	0.063
Metals Test 2	Chromium	0.168	0.0074
Isocyanates Test 1	HDI	<0.0025	<0.0025
Isocyanates Test 2	HDI	<0.0033	<0.0034

[a]< = Compound not detected. Values listed are one-half the MDL.
[b]NA = Not applicable.
[c]N.A. = Not available due to equipment failure.

1. Vertical Distribution

The samples were collected at six different heights across the 14-foot-high exhaust face: 1.5, 4.5, 6.5, 7.5, 10.6, and 13 feet. The fraction of pollutants found at or below each height defines the fraction of hazardous constituents exhausted to a VOC control system with the implementation of split-flow ventilation. This exhausted fraction is the definition of a in the mass balance calculations in Section II.

Figure 12 shows the fractions of total organics, metals, particulate, and isocyanates that were measured at or below each of the specified booth heights. Because two tests were conducted for each pollutant category, and four samples per test were collected at each height, each plotted point in Figure 12 represents the average of eight data points.

Approximately half of the pollutants were found at or below a height of 1.5 feet. Of the toxic constituents, 96 percent were at or below 7.5 feet, and 98 percent were at or below 10.6 feet. Thus, if split-flow ventilation (without recirculation) was implemented in Booth 2, with a split height of 7.5 feet, about 96 percent of the pollutants would exhaust through the lower duct to a VOC control device.

2. Position of "Split"

The vertical distribution data and the maximum concentrations measured in the exhaust duct were used to calculate an appropriate split height and percent recirculation for the split-flow/recirculating ventilation test series. The maximum split height and percent recirculation were restricted by industrial hygiene standards. The 8-hour average equivalent exposure was compared to the Air Force exposure limit to ensure that the exposure during split-flow/recirculating ventilation would not exceed industrial hygiene standards.

The following equation, derived in Section II, was used to calculate the concentrations of toxic constituents in the recirculated air stream in split-flow/recirculating ventilation mode:

$$C_t = C_{unmod}\left(\frac{1 - a}{Ra}\right) \tag{14}$$

where:

C_t = Concentration in top section of exhaust plenum
C_{unmod} = Concentration in unmodified booth
a = The fraction of pollutants found below the split height
R = The recirculation ratio

Because the recirculating air stream mixes with the fresh air stream prior to entering the booth, the concentration reentering the booth in the split-flow/recirculating ventilation mode (C_{in}) becomes

$$C_{in} = \frac{C_t Q_t}{(Q_t + Q_b)} = C_t R \tag{15}$$

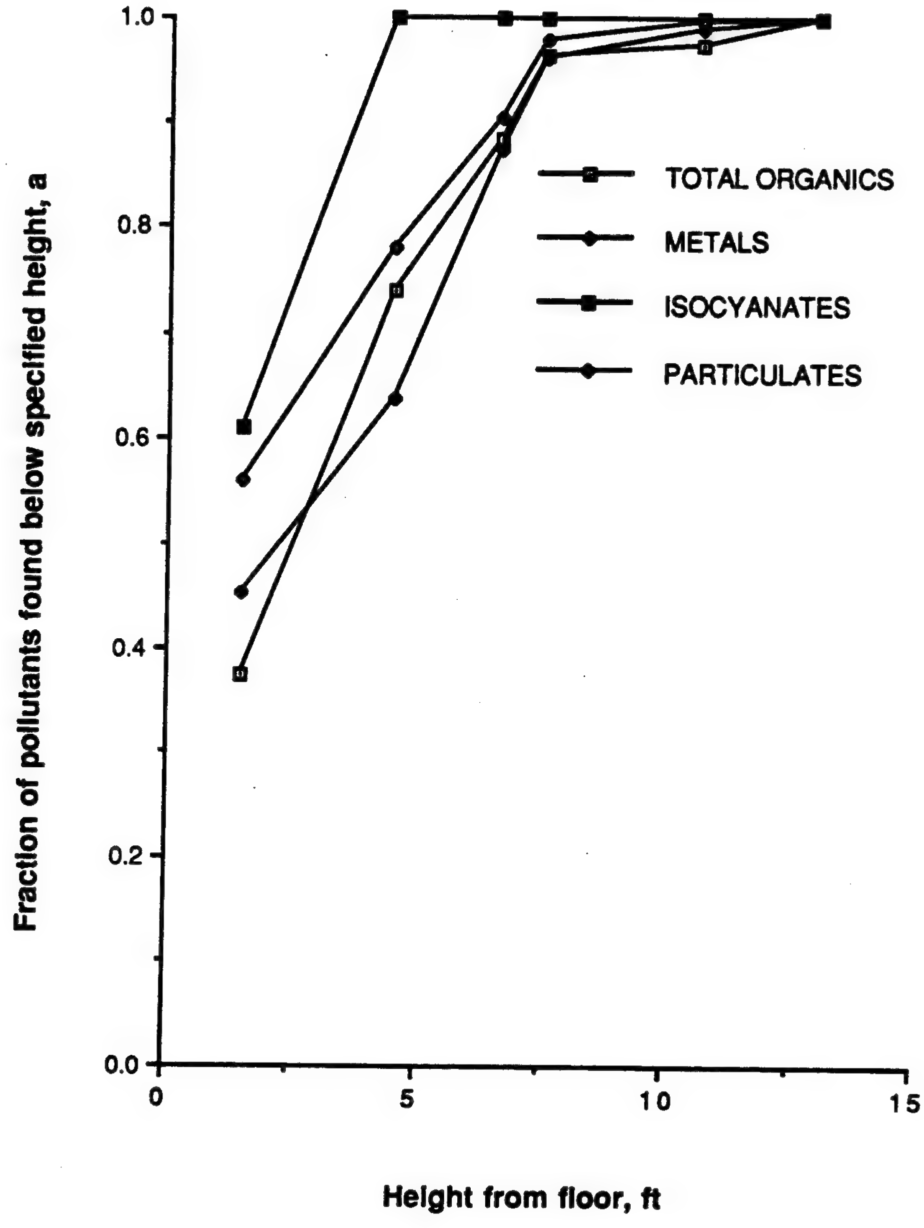


Figure 12. Vertical Distribution of Paint Constituents at the Exhaust Face.

where:

C_{in} = The concentration at the intake face in the split-flow/recirculating ventilation mode

Substituting for C_t gives

$$C_{in} = \frac{C_{unmod}\,(1 - a)}{a} \tag{16}$$

C_{in} was calculated for each toxic constituent and then compared to the PEL value. The value of a was determined for each split height, based on the data in Figure 12. The value of C_{unmod}, the concentration in the unmodified booth, was based on the maximum concentrations observed in the exhaust duct during the baseline tests. These values are tabulated in Table 11.

The equivalent exposure of the pollutants reentering the booth was calculated using equation (1) in Section II and using the OSHA PELs and ACGIH TLVs for that period of time, 1991-92. The objective was to ensure that the incremental addition to the exposure was much less than allowable limits. According to 29 CFR 1910.1000, an E_m value greater than unity (1.0) implies that the toxicity level exceeds the exposure limit during an 8-hour work shift of a 40-hour work-week. An E_m less than unity implies that the equivalent exposure for the air mixture is within acceptable limits. However, the HQ AFLC/SGBE imposed a safety factor of 4, reducing the acceptable E_m value to 0.25.

The incremental equivalent exposures were calculated for two different cases. The first case assumed that the painter was exposed to the concentrations in the booth for the entire 8-hour workday. The second assumed that the painter was subjected to the booth conditions for only 2 hours of each workday, and was exposed to background concentrations, assumed to be zero, for the remaining 6 hours of each workday.

Figure 13 shows the incremental change in E_m corresponding to the various split heights. As the split height decreases, the intake E_m increases. The results indicate that with a split height at or below 6.6 feet, the intake E_m for metals exceeds the HQ AFLC/SGBE criterion of 0.25 (if personnel are exposed in a booth throughout an 8-hour workday). The final split height selected was 7.5 feet, for an estimated 8-hour exposure intake E_m for metals of 0.09 and a 2-hour exposure intake E_m for metals of 0.022. This corresponds to about 40-percent recirculation, because the height of the exhaust face through which air actually flows is 12 feet, whereas the height of the booth is 14 feet. This split height and percent recirculation were considered sufficient to determine the consequences of recirculation while ensuring that the concentrations of pollutants reentering the booth were well below applicable safety limits.

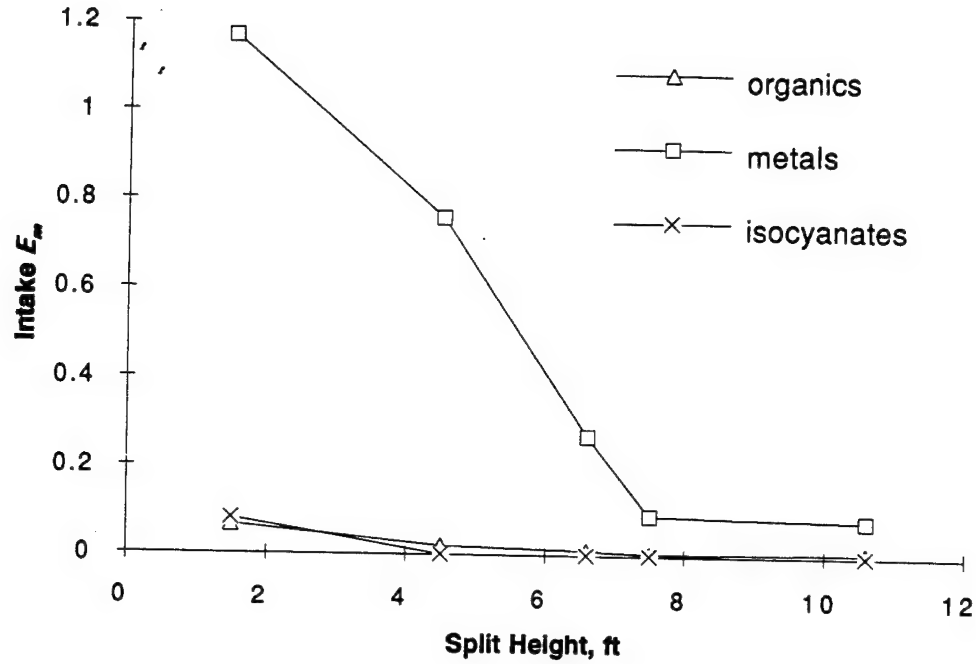
Tables 12 and 13 present the intake E_m results for the split height of 7.5 feet. Table 12 was prepared assuming that the painter is exposed to the concentrations in the booth throughout the workday. Table 13 was prepared assuming that the painter is exposed to booth concentrations for only 2 hours of each workday. In both cases, the E_m values at the intake are far below the HQ AFLC/SGBE criterion of 0.25. In each case, the primary factor is the hexavalent chromium originating from strontium chromate. All of the intake concentration calculations, including those for chromium, were based on the baseline concentrations in the exhaust duct. Because the strontium chromate is particulate matter that should be collected at the intake face particulate filters, these calculations are considered very conservative.

TABLE 11. MAXIMUM CONCENTRATIONS OF POLLUTANTS MEASURED IN THE EXHAUST DUCT DURING THE BASELINE TEST SERIES.

Compound	Test	Type of Paint Used	Highest Exhaust Duct Concentration (mg/m^3)
Zinc	Metals Test 1	Primer	<0.0083[a,b]
Lead	Metals Test 1	Primer	<0.0083[a,b]
Chromium	Metals Test 1	Primer	0.042
MDI	Isocyanates Test 1	Topcoat	<0.0038[a,b]
TDI	Isocyanates Test 1	Topcoat	<0.0038[a,b]
HDI	Isocyanates Test 1	Topcoat	<0.0038[a]
MEK	Isocyanates Test 1	Topcoat	5.8
MIBK	Organics Test 1	Topcoat	4.2
n-Butyl acetate	Organics Test 1	Topcoat	1.1
Toluene	Organics Test 1	Topcoat	0.64
Xylenes	Metals Test 1	Primer	<0.11[a]
Ethyl acetate	Metals Test 1	Primer	<0.26[a]
2-Butanol	Metals Test 1	Primer	<0.28[a]
Methoxyacetone	Metals Test 1	Primer	<0.73[a,b]
Ethoxyethanol	Metals Test 1	Primer	<0.95[a,b]
Ethylbenzene	Metals Test 1	Primer	<0.11[a]
PGMEA	Metals Test 1	Primer	<0.26[a,b]
2-Ethoxyethyl acetate	Metals Test 1	Primer	<0.55[a,b]
2-Methoxyethyl ether	Metals Test 1	Primer	<0.70[a,b]

[a]One-half of method detection limit.
[b]Not identified in MSDS as a constituent of the topcoat or primer.

(a) 8-Hour Exposure



(b) 2-Hour Exposure

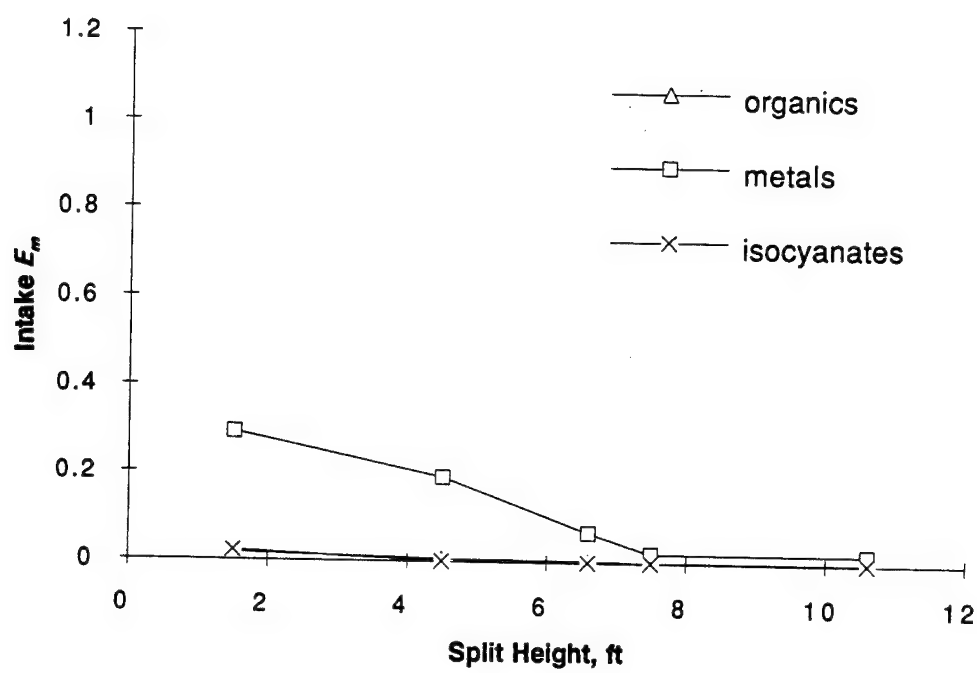


Figure 13. Intake E_m Versus Split Height.

TABLE 12. E_m AT THE INTAKE OF A SPLIT-FLOW/RECIRCULATING VENTILATION PAINT SPRAY BOOTH, ASSUMING 40-PERCENT RECIRCULATION AND 8 HOURS OF EXPOSURE PER DAY.

Compound	1991-92 ACGIH TLV (mg/m^3)	1991-92 OSHA PEL (mg/m^3)	Booth Intake Concentration During Split-flow/ Recirculating Ventilation	
			C_{in} (mg/m^3)	C_{in}/(PEL or TLV)[a]
Hexavalent chromium	0.05	0.05	0.0043	0.09
HDI	0.034	0.04	0.00	0.00
MEK	590	590	0.56	0.00095
MIBK	205	205	0.406	0.0020
n-Butyl acetate	713	710	0.106	0.00015
Toluene	377	375	0.062	0.00017
Xylenes	434	435	<0.011[b]	2.5×10^{-5}
Ethyl acetate	1,440	1,400	<0.025	1.8×10^{-5}
2-Butanol	305	305	<0.027	8.9×10^{-5}
Equivalent exposure (E_m) for the organics				0.0034

[a] E_m calculations based on the PEL or TLV, whichever is the smaller number for each compound.
[b] < = Compound not detected. Values listed are one-half the MDL.

TABLE 13. E_m AT THE INTAKE OF A SPLIT-FLOW/RECIRCULATING VENTILATION PAINT SPRAY BOOTH, ASSUMING 40-PERCENT RECIRCULATION AND 2 HOURS OF EXPOSURE PER DAY.

Compound	1991-92 ACGIH TLV (mg/m^3)	1991-92 OSHA PEL (mg/m^3)	Booth Intake Concentration During Split-flow/ Recirculating Ventilation	
			C_{in} (mg/m^3)	C_{in}/(PEL or TLV)[a]
Hexavalent chromium	0.05	0.05	0.0011	0.022
HDI	0.034	0.04	0.00	0.00
MEK	590	590	0.140	2.4×10^{-4}
MIBK	205	205	0.101	5.0×10^{-4}
n-Butyl acetate	713	710	0.0265	3.7×10^{-5}
Toluene	377	375	0.0155	4.1×10^{-5}
Xylenes	434	435	<0.0028[b]	6.3×10^{-6}
Ethyl acetate	1,440	1,400	<0.0062	4.5×10^{-6}
2-Butanol	305	305	<0.0068	2.2×10^{-5}
Equivalent exposure (E_m) for the organics				0.0008

[a] E_m calculations based on the PEL or TLV, whichever is the smaller number for each compound.
[b] < = Compound not detected. Values listed are one-half the MDL.

SECTION V

POSTMODIFICATION TEST MATRIX AND RESULTS

A 3-week test series was conducted during June and July 1992 to characterize postmodification booth operations, again using Booth 2 as the test site. The postmodification test matrix is summarized in Tables 14 and 15. In the combined split-flow/recirculating ventilation mode, six sampling events occurred for organics, and five for each of the following parameters: particulate, isocyanates, and metals. In the split-flow ventilation mode, three sampling events were conducted: two for particulate and one for organics.

Throughout this section, the exhaust conduit from the lower plenum is referred to as the split-flow duct and the exhaust conduit from the upper plenum as the recirculation duct.

A. SAMPLING LOCATIONS

Figure 14 shows the test locations. These include the two intake faces (site A), over and under the painter's airline respirator hood (Site B), the exhaust face (Site C), and in the split-flow and recirculation ducts (Sites D and E). Site E1 was used during the split-flow/recirculating ventilation tests; Site E2 was used during the split-flow, single-pass tests.

The concentration of organics entering the booth was monitored at Site F. The monitor continuously recorded duct concentration, and also activated an automatic control system that converted the booth into single-pass operation whenever the measured concentration exceeded a preset concentration.

Because the recirculated stream is mixed with fresh intake air, the VOC concentration measured at the feedback FID is lower than the bulk concentration exiting the booth through the recirculation duct. During the initial split-flow/recirculating ventilation tests, the feedback FID was positioned just downstream of the fresh air mixing point. Because the data indicated that the flow was not well mixed at that location, the feedback FID sampling location was moved to just upstream from one of the booth intake faces. This location yielded a more representative bulk VOC concentration.

Three sampling locations were used at each of the two intake faces. The intake sampling locations are illustrated in Figure 15. The sampling locations at the exhaust face were identical to the locations used in the baseline test series, illustrated in Figure 7 (see Section IV).

B. SAMPLING METHODS

For the postmodification test series, the sampling and analytical methods used were the same as those employed during the baseline test series (see Section IV), with one exception: the isocyanate tests in the vicinity of the painter and in the two ducts were conducted using NIOSH Method 5521, an impinger method. This type of method was selected so that, in the event monomeric isocyanates were present in the flow, they would be collected in the impinger solution.

Because the results of this test series are used to determine whether the combined split-flow/recirculating ventilation strategy is safe and practical, it was important that the organic, particulate, metal, and isocyanate concentrations in the ventilation ducts be accurately

TABLE 14. SAMPLING MATRIX FOR SPLIT-FLOW/RECIRCULATING VENTILATION TESTS.

Parameter	Sampling Location	Sampling Method	Number of Tests
Organics	Split-flow and recirculation ducts	NIOSH Method 1300[a] BAAQMD Method ST-7[b] EPA Method 25A[c]	21 21 21
	Exhaust and intake faces, painter vicinity	NIOSH Method1300	6
Particulate	Split-flow and recirculation ducts	EPA Method 5[c]	16
	Exhaust and intake faces, painter vicinity	NIOSH Method 500[a]	5
Metals	Split-flow and recirculation ducts	EPA Draft Multiple Metals[d]	5
	Exhaust and intake faces, painter vicinity	NIOSH Method 7300[a]	5
Isocyanates	Split-flow and recirculation ducts	NIOSH Method 5521[a] OSHA Method 42[e]	5 1
	Exhaust and intake faces	OSHA Method 42	5
	Painter vicinity	NIOSH Method 5521	5
Flow rate	Split-flow duct	EPA Method 2[c]	21
	Exhaust and intake faces	ACGIH[f]	18
Paint usage	Booth	Gravimetric	21
Paint % volatile, density	Booth	Grab	1 sample per paint type used

[a]Reference 7.
[b]Reference 8.
[c]Reference 9.
[d]Reference 10.
[e]Reference 11.
[f]Reference 12.

TABLE 15. SAMPLING MATRIX FOR SPLIT-FLOW TESTS.

Parameter	Sample Location	Sampling Method	Number of Tests
Organics	Split-flow and recirculation ducts	NIOSH Method 1300[a] BAAQMD Method ST-7[b] EPA Method 25A[c]	3 3 3
	Exhaust and intake faces, painter vicinity	NIOSH Method 1300	1
Particulate	Split-flow and recirculation ducts	EPA Method 5[c]	3
	Exhaust and intake faces, painter vicinity	NIOSH Method 500[a]	2
Flow rate	Split-flow duct	EPA Method 2[c]	3
	Exhaust and intake faces	ACGIH[d]	3
Paint usage	Booth	Manual recording	3
Paint % volatile, density	Booth	Grab	1 sample per paint type used

[a]Reference 7.
[b]Reference 8.
[c]Reference 9.
[d]Reference 12.

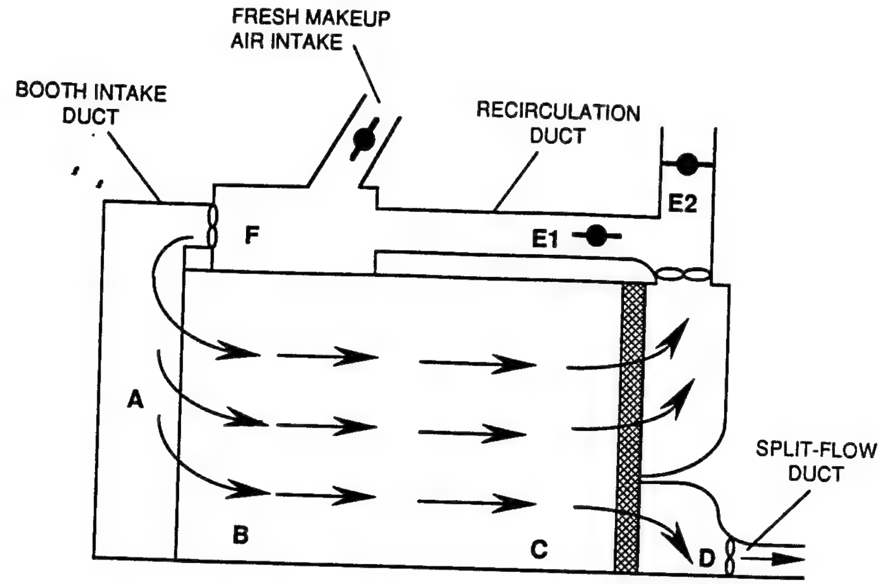


Figure 14. Sampling Locations for the Postmodification Test Series.

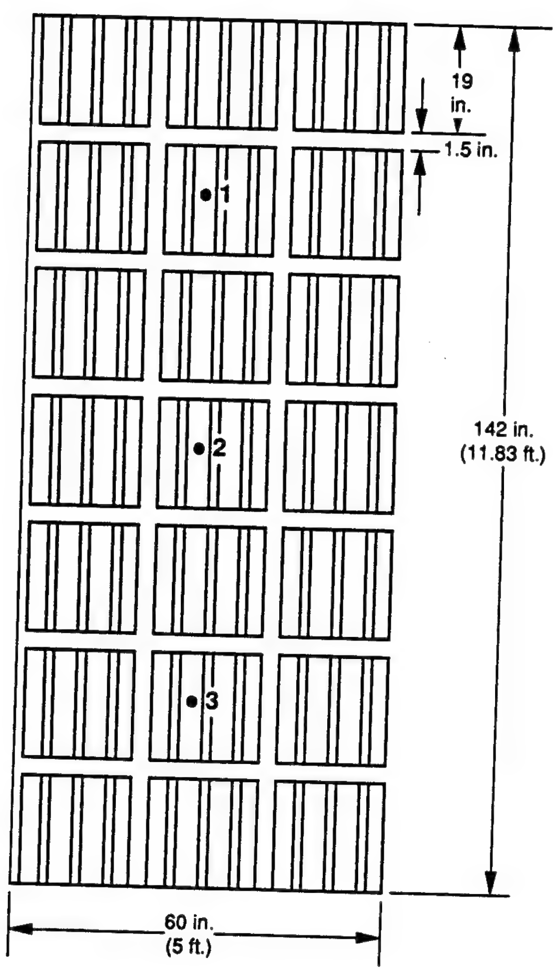


Figure 15. Sampling Locations at One of Two Intake Faces.

determined. An additional objective was to compare concentration profiles of these compounds at the exhaust face of the booth with the concentration profiles obtained in the baseline test series. The sampling methods were selected to safely achieve these objectives and obtain accurate results. The selection process used to identify appropriate sampling procedures is presented in Section IV.B.

C. RESULTS OF PAINT CONSUMPTION DURING THE POSTMODIFICATION TEST SERIES

Three types of paint were used in Booth 2 during the postmodification test series: water-borne epoxy primer, polyurethane topcoats, and water-borne acrylic topcoats. The epoxy primer and polyurethane topcoats are two-part coatings. The epoxy primer is mixed at a 3-to-1 epoxy-to-curing-solution volume ratio, and the polyurethane topcoats are prepared in a 3-to-1 pigment-to-catalyst volume ratio (green and gunship gray) or a 1-to-1 pigment-to-catalyst volume ratio (other pigments). The acrylic topcoats required mixing the pigment with water in a 3-to-1 ratio. Paint samples were collected and analyzed for density and percent volatiles. The results are presented in Table 16.

Paint usage was monitored by a field crew member, stationed in the booth, who recorded the type of paint used, the total weight of paint used during the test event, and the type and size of the object painted. The paint usage data are summarized in Table 17.

D. AIR FLOW RATE MEASUREMENTS

Prior to testing, the fans were balanced to achieve flow characteristics similar to those observed during the baseline testing. The face velocity through the booth was 100 fpm, corresponding to a volumetric flow rate of about 25,200 cfm. Table 18 lists the flow rate results for the booth intake, the split-flow duct (lower plenum), and the recirculation duct (upper plenum).

The booth intake velocity was measured after each test using an anemometer. The face was divided into sections and the velocity was measured in the center of each section. The volumetric flow rate was calculated using the following equation:

$$Q = \sum (v_i A_i) \tag{17}$$

in which:

Q = Volumetric flow rate at the booth face
v_i = Velocity measured at the center of section i using an anemometer
A_i = Area of section i

The intake face flow rate values were corrected from cfm to dscfm based on the correction factor calculated for the split-flow duct.

The volumetric air flow rate in the split-flow duct was measured during every sampling event. The flow rate in the recirculation duct was determined by subtracting the split-flow duct flow rate from the total booth intake flow rate. The site for the recirculation duct sampling did not meet the EPA Method 1 criterion (greater than two stack diameters downstream from a duct

TABLE 16. RESULTS OF PAINT DENSITY AND PERCENT VOLATILE ANALYSES.

Paint Type	Percent Volatile Analysis			Density Measurement			
				Measured Density		Published Density	
	Initial Weight (g)	Final Weight (g)	Percent Volatile	Pigment or Epoxy (kg/L)	Catalyst or Curing Solution (kg/L)	Pigment or Epoxy (kg/L)	Catalyst or Curing Solution (kg/L)
DI Water Blank	7.0	0	100	(NA)[a]	(NA)	1.0	1.0
Lt. Green Primer MIL-P-85582A	18.1	7.4	59.1	1.33	1.04	1.29	1.01
Drk. Green Top Coat MIL-C-85285B, 34092,G/S,Type I	9.0	5.6	37.8	1.20	1.09	1.194	1.080
Gray Top Coat MIL-C-85285B, 16473, Type I	10.1	6.6	34.7	1.36	0.934	1.396	0.969
Acrylic Gloss Red Top Coat	21.9	6.2	71.7	1.06	1.01	1.055	1.000
Acrylic Gloss (Water Reducible) Blue Top Coat	20.9	7.3	65.1	1.19	1.01	1.181	1.000
Gunship Gray Top Coat MIL-C-85285B, 36118,G/S,Type I	15.8	10.1	36.1	1.22	1.09	1.403	1.080
Gray Top Coat MIL-C-85285B, 36173, Type I	12.2	8.5	30.3	1.18	1.07	1.233	1.080
White Top Coat MIL-C-85285B, 17925, Type I	10.8	7.5	30.6	1.47	0.943	1.473	0.969
White Top Coat MIL-C-85285B, 17925, Type I (QA Duplicate)	12.1	8.2	32.2	1.45	0.970	1.473	0.969

[a](NA) = Not analyzed.

TABLE 17. PAINT CONSUMPTION RATES DURING POSTMODIFICATION TEST SERIES.

Date and Test	Approximate Test Time (minutes)	Time	Paint/Solvent Type	Quantity (kg)	Painted Object	Comments
16 June 1992, Organics Test 1	81	1319-1322 1351-1402 1430-1431 1442-1505 1508-1509	Green Primer MEK Gray 16473 MEK	0.995 0.269 N.A.[b] N.A.[b]	Auxiliary Ramps (7 ft L x 2 ft W x 1 ft H)[a] two on 3-ft-H table	Lost power from 1322 to 1351
17 June 1992, Organics Test 2	46	1000-1007 1011-1018 1021-1022 1030-1036 1038-1043 1045-1046	Green Primer MEK Gray 16473 MEK	0.519 0.447 0.183 0.485 0.499 0.193	Auxiliary Ramps, same as above, turned over	Added paint twice for each color (start and middle) 1042: painter kneeling with back to grid pointing paint gun up under object
17 June 1992, Organics Test 3	43	1518-1523 1525-1531 1532-1533 1541-1548 1551-1555 1557-1601	Green Primer MEK Dark Green 	0.475 0.536 0.266 0.574 0.372 0.617	Large wood & metal box (3.5 ft L x 3 ft W x 2 ft H) on 2.5-ft-H table	Painter kneeled and sprayed MEK through paint gun toward grid. 1545, 1553: painter facing away from grid
18 June 1992, Organics Test 4	25	0949-0957 0959-1009 1012-1014	Green Primer MEK	0.457 0.420 0.342	Ladders (2) (6.5 ft L x 2 ft W) against left wall 4 & 7 ft from grid	Painted folded, unfolded, and turned over
19 June 1992, Particulate Test 1	37	0825-0839 0841-0847 0849-0857 0900-0902	White MEK	0.486 0.263 0.167 0.300	Ladders (2) 5 & 7 feet from grid against left wall	Ladders painted partially folded, not turned over
19 June 1992, Particulate Test 2	33	1400-1405 1408-1413 1416-1422 1424-1430 1432-1433	Green Primer MEK	0.570 0.543 0.471 0.515 0.228	Bowser (8 ft L x 5 ft W x 8 ft H) mostly centered in room	1412-1416, 1426: painter facing away from grid
22 June 1992, Particulate Test 3	68	0959-1018 1020-1022 1031-1039 1042-1107	White MEK Safety Red 	0.423 0.339 0.636 0.683	Ladders (2) and Bowser	1016: pump fell off painter's belt Paint gun cleaned with water after painting with red paint completed

CONTINUED

[a]L = long, W = wide, H = high.
[b]N.A. = Not available. Final paint gun weight not obtained.

TABLE 17. PAINT CONSUMPTION RATES DURING POSTMODIFICATION TEST SERIES (CONTINUED).

Date and Test	Approximate Test Time (minutes)	Time	Paint/Solvent Type	Quantity (kg)	Painted Object	Comments
22 June 1992, Metals Test 1	41	1412-1418 1420-1428 1432-1449 1452-1453	Green Primer MEK	0.646 0.900 0.680 0.334	Comfort Pallet (6 ft L x 6 ft W x 7.5 ft H)[a] on skids 1 ft off floor (top, inside latrines & kitchen)	Painter inside pallet for 25 minutes of test
23 June 1992, Metals Test 1 (continued)	33	0735-0749 0758-0810 0808 stopped traverse 0811-0812	Green Primer MEK	1.054 0.252	Comfort Pallet (sides and flat plates)	No grid samples 0751-0758: painter inside pallet; sample outside of painter respirator was detached
23 June 1992, Isocyanates Test 1	55	1027-1050 1054-1109 1111-1119 1121-1122	White MEK	0.804 1.067 0.631 0.241	Comfort Pallet (kitchen and latrines)	Sample outside of painter respirator was reattached at 1050; inside pallet, 1100-1119
23 June 1992, Organics Test 5	54	1440-1454 1457-1507 1510-1523 1525-1529 1433-1434	White MEK	0.901 0.784 1.021 0.393 0.214	Comfort Pallet (kitchen & latrines)	MEK sprayed; painter pointed paint gun left, parallel to grid
24 June 1992, Particulate Test 4	63	0920-0926 0930-0946 0950-0957 1011-1023 1023	Light Blue MEK	0.891 0.952 0.574 0.478 0.264	Comfort Pallet (sides and top)	0926: Sample outside of painter respirator was reattached Power loss: booth switched to single-pass twice, 0956-1006
24 June 1992, Metals Test 2	63	1427-1444 1449-1508 1512-1526 1529-1530	Green Primer MEK	0.569 0.570 0.640 0.417	Splitters (4) (3 ft L x 2 ft W x 2 ft H) on 2.5-ft-H table	MEK sprayed, painter facing grid
25 June 1992, Metals Test 3	52	0838-0854 0856-0927 0929-0930	Green Primer MEK	0.528 0.643 0.280	Brake parts (5) (18-in-diameter x 1.5-in-W) Wheel hubs (10) (18-in-diameter x 1-ft-H) Ramp (7 ft L x 4 ft W x 2.5 ft H) on 2.5-ft-H tables	0839-0840: Masking MEK sprayed, painter kneeling 1.5 ft from grid, parallel to grid

[a]L = long, W = wide, H = high.

CONTINUED

TABLE 17. PAINT CONSUMPTION RATES DURING POSTMODIFICATION TEST SERIES (CONTINUED).

Date and Test	Approximate Test Time (minutes)	Time	Paint/Solvent Type	Quantity (kg)	Painted Object	Comments
25 June 1992, Isocyanates Test 2	61	1126-1156 1159-1224 1226-1227	White MEK	0.931 0.882 0.228	Brake parts (5) Wheel hubs (10) Ramp on 2.5-ft-H tables	MEK sprayed; painter kneeling; paint gun angled down toward grid
25 June 1992, Isocyanates Test 3	50	1452-1531 1534-1542 1544-1545	Gunship Gray MEK	0.734 0.377 0.224	Splitters (4) 2 on ground, 2 on table	Painter sprayed MEK while standing; paint gun angled down toward grid
26 June 1992, Metals Test 4	73	0838-0857 0901-0919 0923-0925 0933-0943 0946-0951 0954-0955	Green Primer MEK	0.429 0.745 0.026 0.725 0.276 0.214	Thrust Reverser (7-ft-diameter x 3.5-ft-H)[a] on 2.5-ft-H cart (inside and outside)	0924-0929: lost power; booth converted to single-pass Painter sprayed MEK while standing; paint gun angled down toward grid; then painter kneeling, parallel to grid
26 June 1992, Metals Test 5	71	1132-1156 1159-1212 1215-1222 1233-1240 1242-1243	Gunship Gray MEK	0.900 0.978 0.832 0.942 0.274	Thrust Reverser	1222-1230: Painter left booth to get more paint Painter sprayed MEK down and left, while standing.
29 June 1992, Particulate Test 5	64	1344-1413 1416-1444 1447-1448	Green Primer MEK	0.600 0.487 0.316	QEC Panels (7) (2 ft L x 2.5 ft W x 1 ft H)[a] (concave) on 2.5-ft-H tables	Painter sprayed MEK to left, kneeling, parallel to grid
30 June 1992, Isocyanates Test 4	58	0804-0826 0829-0845 0848-0858 0901-0902	Gunship Gray MEK	0.798 0.831 0.600 0.347	QEC Panels (7)	Painter sprayed MEK back and left; paint gun angled slightly down
30 June 1992, Isocyanates Test 5	53	1106-1133 1136-1155 1158-1159	Green Primer MEK	0.603 0.625 0.172	C-141 Engine (6-ft-diameter x 25-ft-L) on 2.5-ft-H cart	Painter sprayed MEK left; paint gun angled down, parallel to grid
30 June 1992, Organics Test 6	60	1439-1452 1501-1514 1517-1525 1528-1535 1538-1539	Gunship Gray MEK	0.794 0.723 0.549 0.466 0.233	C-141 Engine	1452-1501: Painter waiting for more paint Painter sprayed MEK while standing; paint gun angled toward grid

[a]L = long, W = wide, H = high.

CONTINUED

TABLE 17. PAINT CONSUMPTION RATES DURING POSTMODIFICATION TEST SERIES (CONCLUDED).

Date and Test	Approximate Test Time (minutes)	Time	Paint/Solvent Type	Quantity (kg)	Painted Object	Comments
1 July 1992, Split-flow Organics Test 1	63	0805-0820 0824-0837 0841-0905 0907-0908	Gray 36173 MEK	0.751 0.606 0.950 0.152	C-141 Engine	0837: Lost power Painter sprayed MEK while standing; paint gun angled down, parallel
1 July 1992, Split-flow Particulate Test 1	57	1103-1122 NA[c] 1130-1144 1149-1200 NA	Green Primer MEK Gunship Gray MEK	0.473 1.597[d] 1.113 1.001 1.620[d]	QEC Panels (9) Ramp (1) Sheetmetal Pieces (3)	Second painter — faster strokes, more overspray MEK sprayed into solvent waste can; remainder poured into can
1 July 1992, Split-flow Particulate Test 2	64	1446-1526 1529 1535-1550	Gunship Gray MEK Gunship Gray	1.125 NA[c,d] 0.962	Wooden Box (4 ft L x 3 ft W x 2 ft H)[a] Stand (7.5 ft H) 2 Sheetmetal (3 ft L x 2 ft W)	Second painter — faster strokes, more overspray MEK sprayed into solvent waste can

[c]NA = Not applicable.
[d]MEK sprayed directly into waste can; no observable MEK emissions.

TABLE 18. VOLUMETRIC FLOW RATES AT INTAKE FACES, SPLIT-FLOW DUCT, AND RECIRCULATION DUCT.

Date	Test Type	Flow Rate (dscfm)			Fraction Recirculation
		Intake Face	Split-flow Duct	Recirculation Duct[a]	
Split-flow/Recirculating Ventilation Tests					
17 June 1992	Organics Test 2	23,126	12,157	10,969	0.47
	Organics Test 3	22,494	12,026	10,468	0.47
18 June 1992	Organics Test 4	27,251	12,410	14,841	0.54
19 June 1992	Particulate Test 1	22,741	12,201	10,540	0.46
	Particulate Test 2	Not measured	12,169	NA[b]	NA
22 June 1992	Particulate Test 3	26,058	12,163	13,895	0.53
	Metals Test 1	25,589	12,135	13,454	0.53
23 June 1992	Isocyanates Test 1	27,625	12,057	15,568	0.56
	Organics Test 5	24,629	11,942	12,687	0.52
24 June 1992	Particulate Test 4	25,740	12,035	13,705	0.53
	Metals Test 2	25,224	11,897	13,327	0.53
25 June 1992	Metals Test 3	Not measured	12,127	NA	NA
	Isocyanates Test 2	21,744	12,189	9,555	0.44
	Isocyanates Test 3	27,157	12,093	15,064	0.55
26 June 1992	Metals Test 4	24,897	12,158	12,739	0.51
	Metals Test 5	26,472	12,223	14,249	0.54
29 June 1992	Particulate Test 5	27,197	12,038	15,159	0.56
30 June 1992	Isocyanates Test 4	28,395	12,117	16,278	0.57
	Isocyanates Test 5	28,587	12,099	16,488	0.58
	Organics Test 6	24,342	12,115	12,227	0.50
Average (± Standard Deviation)		25,500 ±2,000	12,100 ±100	13,400 ±1,200	0.53 ±0.09
Split-flow Ventilation					
1 July 1992	Organics Test 1	23,482	12,338	11,144	NA[c]
	Particulate Test 1	28,221	12,402	15,819	NA[c]
	Particulate Test 2	25,957	12,421	13,536	NA[c]
Average (± Standard Deviation)		25,900 ±2,400	12,390 ±40	13,500 ±1,300	

[a]Calculated by difference.
[b]NA = Not applicable.
[c]NA, not recirculating in split-flow mode.

disturbance); therefore, the flow pattern in the recirculation duct was cyclonic. Consequently, the flow rate was not measured in the recirculation duct.

E. RESULTS OF EXHAUST AND INTAKE FACE MEASUREMENTS

Results of the exhaust and intake face measurements are described below for both the split-flow and the combined split-flow/recirculating ventilation tests. Spreadsheets containing the reduced data are presented in Volume II, Appendix G. The data quality objectives and results are presented in Volume II, Appendix H. The calculated concentrations incorporate the following assumptions:

- Each compound not detected was assumed to be present at one-half the method detection limit (MDL).
- The concentrations at the exhaust and intake faces were determined by averaging concentrations measured at the sampling points located at each individual height.

For all paint constituents measured, the results are consistent with the concentration gradient phenomenon upon which the split-flow concept is based. In addition, the results at the booth intake reaffirm the safety of the recirculation concept, as average concentrations measured at the booth intake were consistently and significantly less than the corresponding OSHA PELs.

1. Organic Compounds

NIOSH Method 1300 was used to define average organic concentrations of individual species during the sampling period. Because NIOSH Method 1300 is an integrated sampling procedure, the results of these tests were not used to draw conclusions regarding instantaneous or peak concentrations, but, rather, the long-term average concentration. This type of data treatment is consistent with both Air Force and OSHA PEL and TLV limits. They are average concentrations over a specified length of time. Thus, conclusions can be drawn from these results regarding the efficiency of the modification to remain within Air Force and OSHA limits.

Figures 16 through 21 present the results of organic measurements during the combined split-flow/recirculating ventilation tests. Figure 22 presents results at the intake and exhaust faces for the one split-flow test. The concentrations reported in these figures represent the sum of all the organic species measured in the NIOSH Method 1300 speciation analyses. The intake face results are indicated by dashed lines, and the exhaust face results by solid lines.

The concentration trends indicated by the plots confirm the finding of previous tests that the solvent concentration at the exhaust face decreases with increasing distance from the painter and painted objects. The variability in the concentration trends from one test to the next is explained by the range of painting conditions, paint types, and object sizes and shapes encountered during testing.

Two types of paint were used during the organics tests, epoxy primer and polyurethane topcoat. Because primer volatiles include both water and VOCs, less total organics are observed during primer painting than during polyurethane topcoat painting. During organics Tests 1, 2, and 3, both primer and topcoat were used. During organics Test 4, only primer was used, and the measured organics concentrations were less than in other tests. During organics Tests 5 and 6, only topcoat was used.

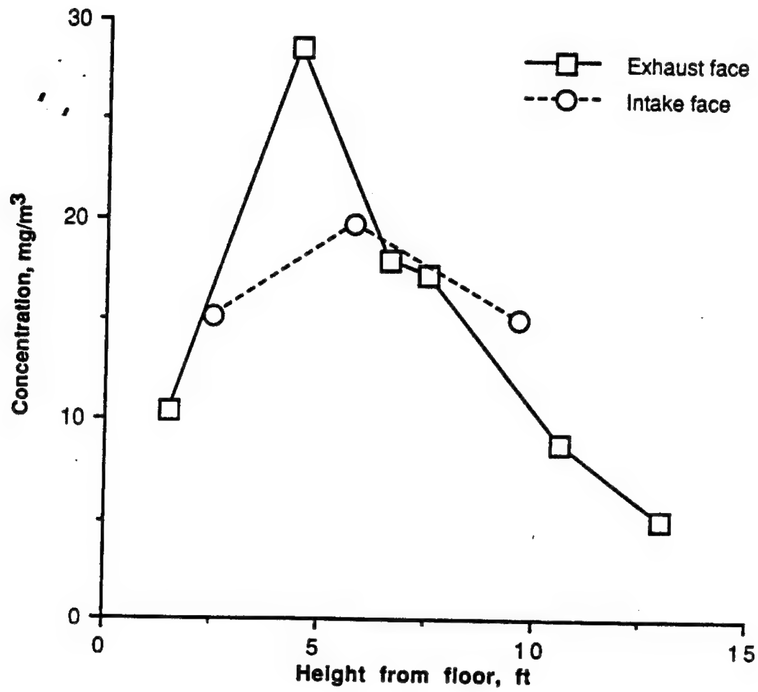


Figure 16. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 1.

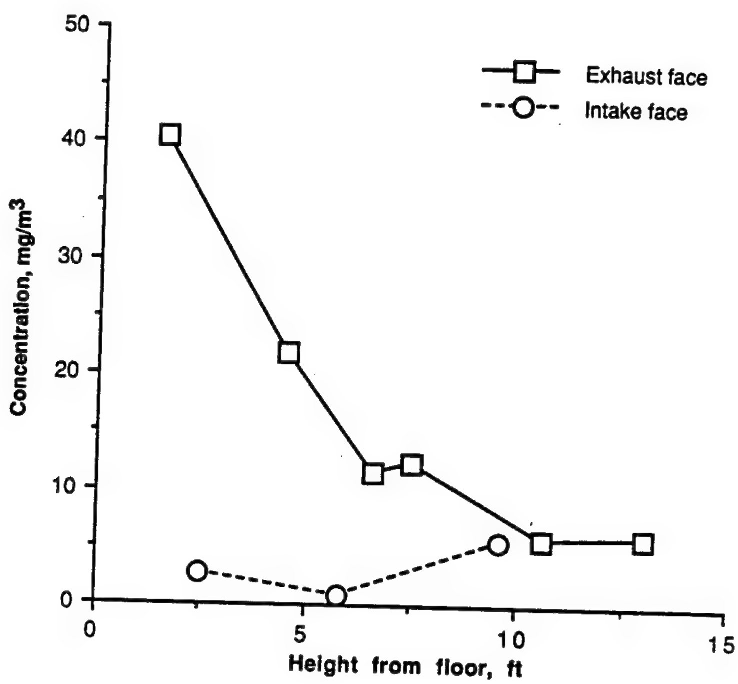


Figure 17. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 2.

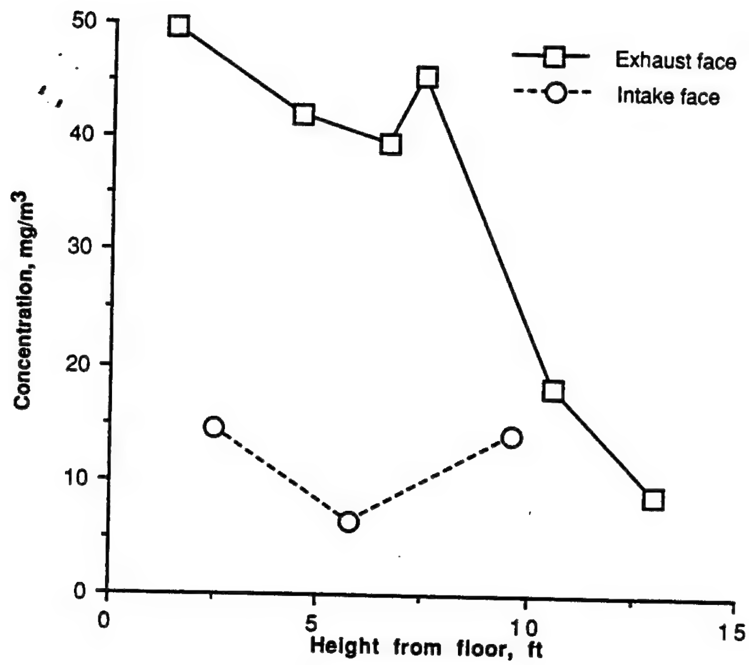


Figure 18. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 3.

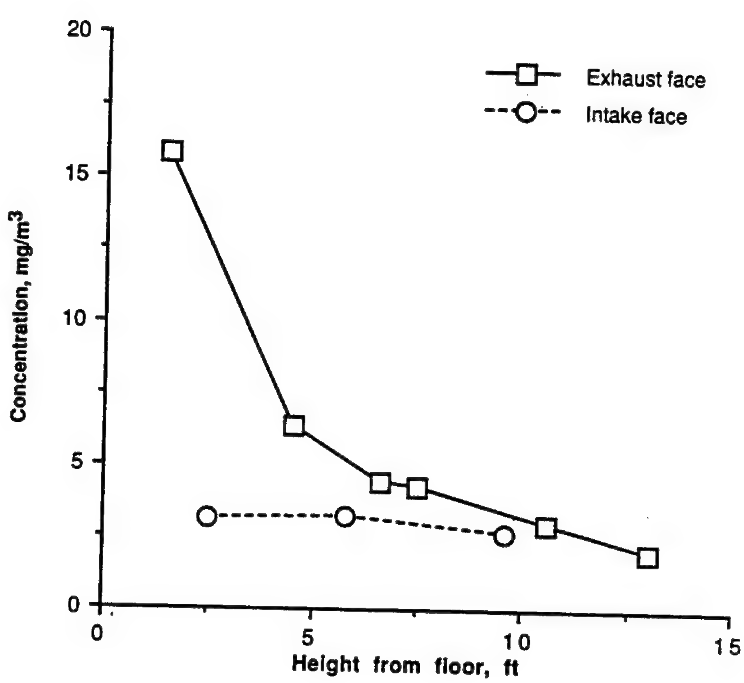


Figure 19. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 4.

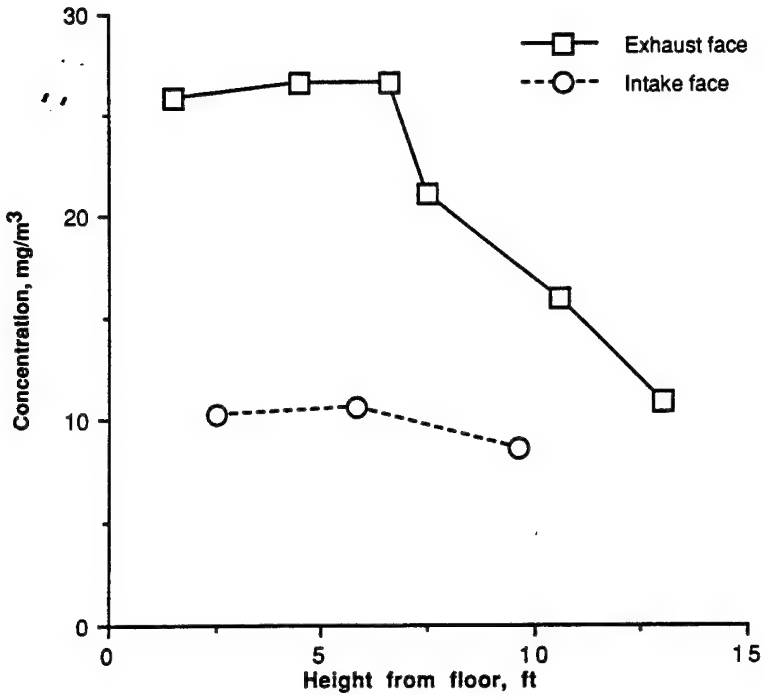


Figure 20. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 5.

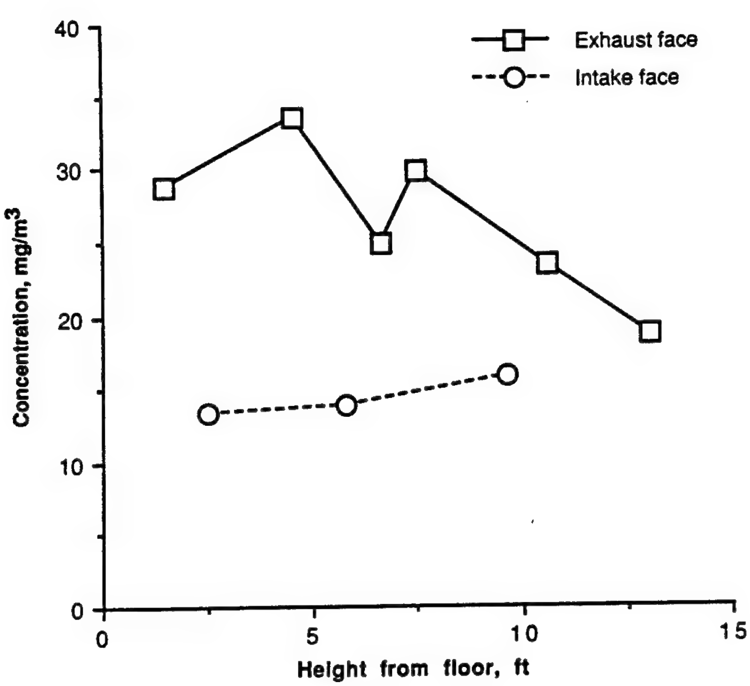


Figure 21. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 6.

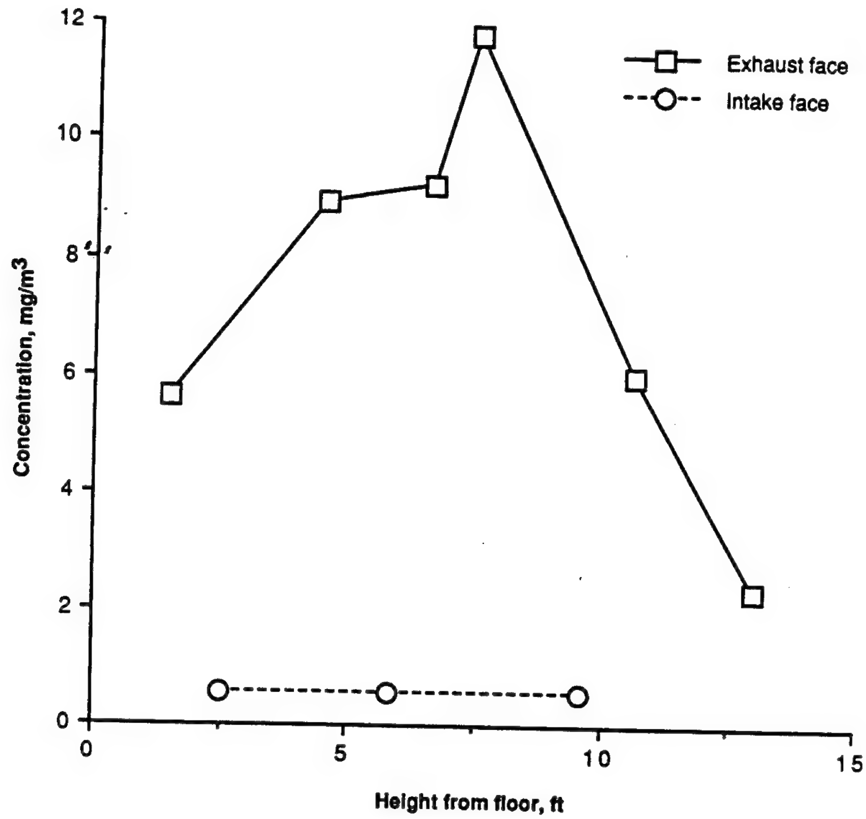


Figure 22. Results of Organic Measurements at the Intake and Exhaust Faces During Split-flow Ventilation—Test 1.

The heights and dimensions of objects painted included a 1-foot-high auxiliary ramp; a 7.5-foot-high comfort pallet; and a 6-foot-diameter, 25-foot-long C-141 engine mounted on a 2.5-foot-high cart. The organics concentrations decrease more rapidly with height for small objects, such as the ramps painted during organics Tests 1 and 2 (Figures 16 and 17), than for large objects, such as the C-141 engine painted during organics Test 6 (Figure 21). For each example, the data confirm the expectation of a top-to-bottom concentration gradient, and the total organic concentration measured at the intake faces is significantly less than the calculated STEL for a paint mixture of 350 ppm (Reference 6).

2. Particulate

Particulate testing was conducted in the booth during the application of epoxy primer, polyurethane topcoat, and water-based topcoat.

Figures 23 through 27 present the particulate concentrations measured at the intake and exhaust faces during combined split-flow/recirculating ventilation. Figures 28 and 29 present the concentrations measured at the intake and exhaust faces during split-flow ventilation. With the exception of one data point, particulate matter was not detected at the booth intake face; all other intake face data on the plots represent one-half the MDL. The single intake value in Figure 24 that is greater than the MDL is an average of two samples obtained at that height (one at each intake face); one sample value was below the detection threshold and assumed to be one-half the MDL, and the other was measured at 7.3 mg/m^3, larger than the average concentrations measured at the exhaust face during that test. The latter value was therefore considered a data outlier. Variability in the particulate profile at the exhaust face may be attributed to the variety of paints used, and the numbers and sizes of the objects painted.

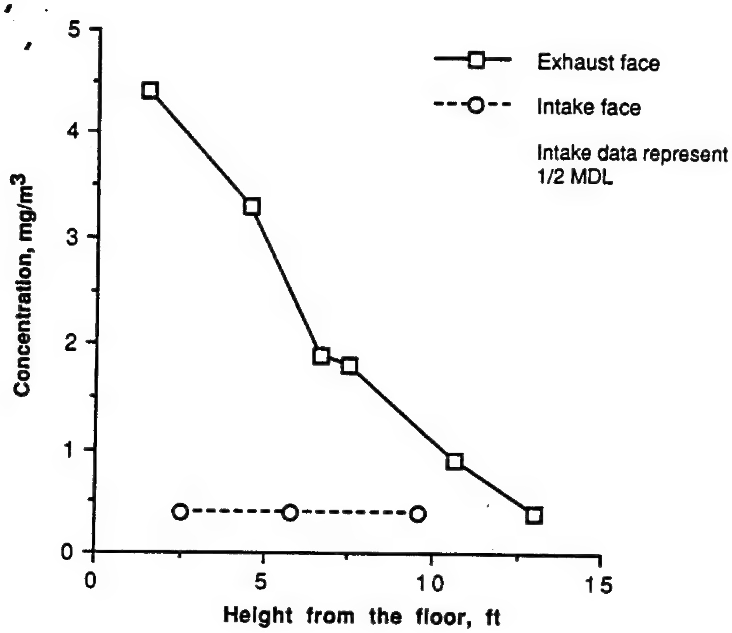


Figure 23. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 1.

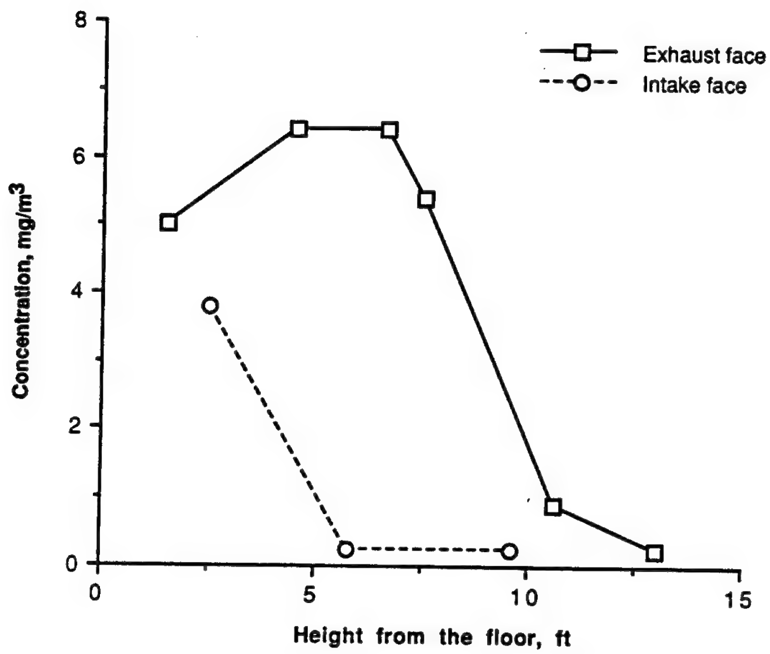


Figure 24. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 2.

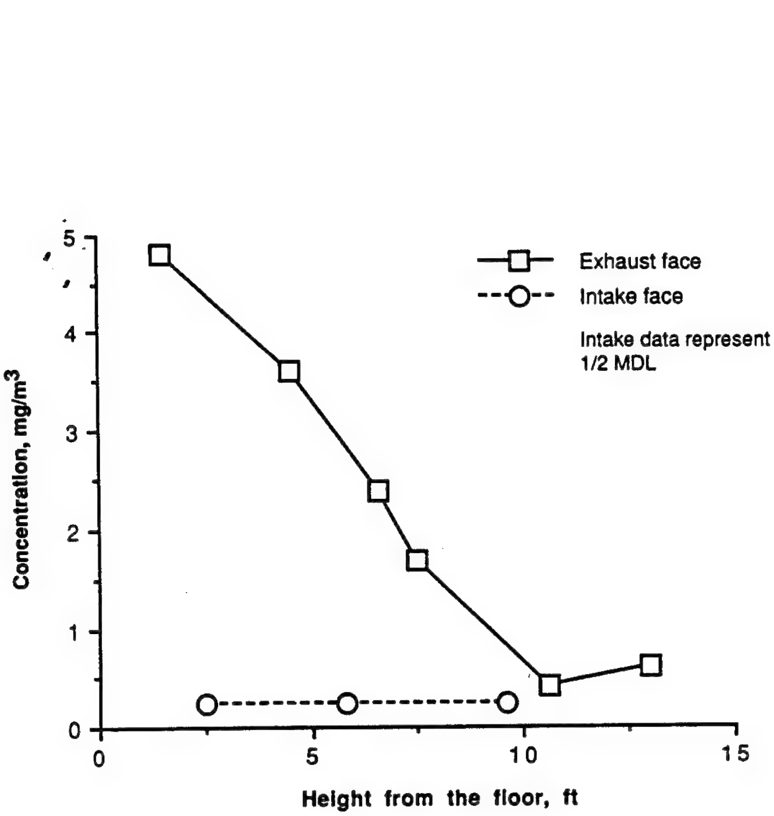


Figure 25. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 3.

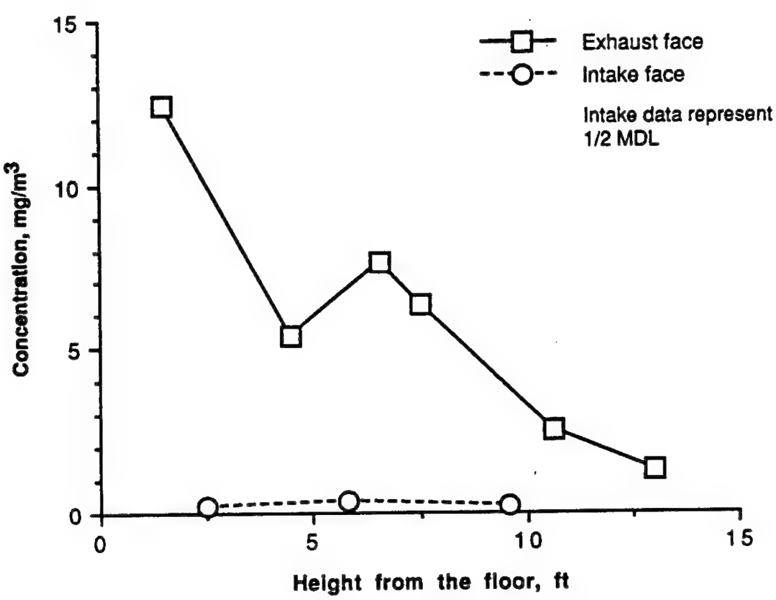


Figure 26. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 4.

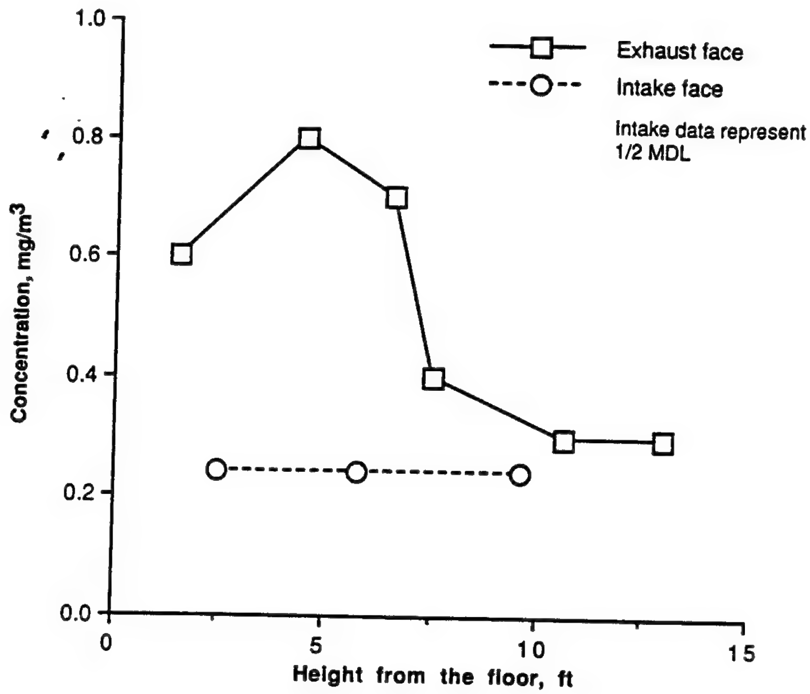


Figure 27. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow/Recirculating Ventilation—Test 5.

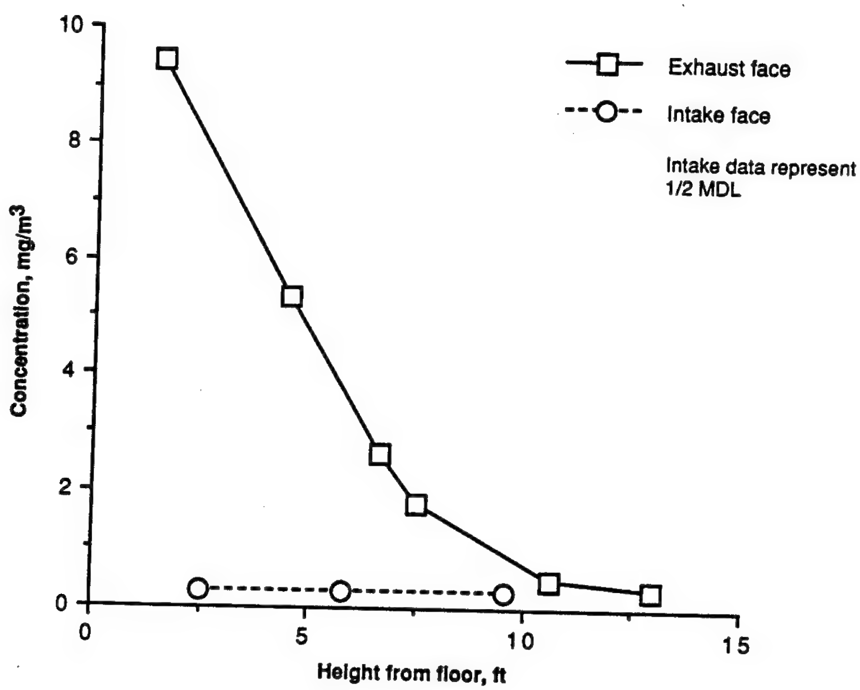


Figure 28. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow Ventilation—Test 1.

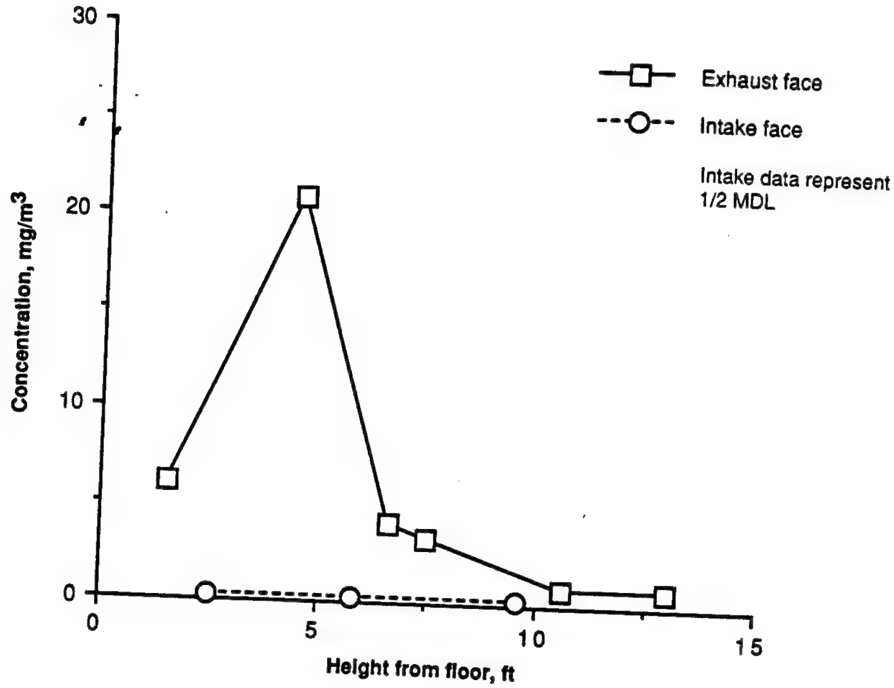


Figure 29. Measured Concentrations of Particulate at the Intake and Exhaust Faces During Split-flow Ventilation—Test 2.

A comparison of particulate Tests 2 and 5 illustrates the dependence of the exhaust face concentration profile on the configuration and orientation of the object. Both tests were conducted during primer painting. Test 2 was conducted during the painting of an 8-foot-high bowser. Test 5 was conducted during the painting of seven concave Quick Engine Change (QEC) panels. The panels were placed on two tables in the center of the booth. The tables were approximately 2.5 feet high and the QEC panels were about 6 inches in height. Comparing the exhaust face profiles in Figures 24 and 27 shows that a higher concentration of particulate was observed during the painting of the bowser. The irregular shape of the bowser made it difficult to paint without significant overspray, whereas applying an even layer of paint to the QEC panels was easier due to their relatively flat shape. The height of the bowser is also evident from Figure 24; particulate was emitted higher up in the booth.

Booth 2, the tested booth, was equipped with two sets of particulate filters, one at the exhaust face (downstream of the exhaust face sampling locations) and one at the booth intake. Because the exhaust face measurements were obtained upstream of the exhaust face particulate filters, the results do not affect the practical use of split-flow/recirculating ventilation, even for large objects. The results indicate that split-flow/recirculating ventilation does not affect the particulate concentration in the booth. All but one of the intake samples were observed to be less than the MDL.

3. Metals

Five sets of metals tests were conducted in the combined split-flow/recirculating ventilation mode. No metals tests were conducted in the split-flow mode. The samples were analyzed for the presence of strontium, chromium, lead, and zinc. Because the primer contains

strontium chromate, metals Tests 1 though 4 were conducted during primer coating. As a background check, metals Test 5 was conducted during topcoat application.

Figures 30 through 34 present the strontium chromate results for the five metals tests. The analytical method for metals measures strontium and chromium individually rather than total strontium chromate. Because the strontium and chromium originated from the strontium chromate in the primer, their measured concentrations were converted into the equivalent strontium chromate concentration. The figures present the strontium chromate concentration profile based on both strontium and chromium test results. The correspondence of the concentration profiles in each figure suggests that the measured strontium and chromium originated only from strontium chromate.

The strontium chromate concentration profile at the exhaust face is consistent with the concentration gradient concept. At heights above the painter and painted objects, the concentration decreases with increasing height. Strontium chromate concentrations at the intake were at or near the MDL, 1 to 3 orders of magnitude below those measured at the exhaust face, suggesting a high removal efficiency at the exhaust face and intake face particulate filters.

Test 5 (Figure 34) was conducted during polyurethane topcoat application. Because this topcoat contains no strontium chromate, little or no strontium chromate was expected to be present, and neither strontium nor chromium was detected in most samples. The vertical axis scale in Figure 34 is 0 to 7 $\mu g/m^3$, compared to 0 to 1,200 $\mu g/m^3$ in Figures 30 and 31, 0 to 600 $\mu g/m^3$ in Figure 32, and 0 to 2,000 $\mu g/m^3$ in Figure 33.

The lead determination results are presented in Figures 35 through 39, and the zinc determination results in Figures 40 through 44. Because no lead or zinc was observed in the baseline test series, it is suspected that their presence in the postmodification test series resulted from nearby sanding operations or from the ducting modifications. The ducting contains welded galvanized steel, which might contain zinc, chromium, lead, nickel, and molybdenum (References 14 and 15). The lead PEL is 100 $\mu g/m^3$; the maximum exhaust face concentration was 21 $\mu g/m^3$. The zinc PEL is 1,000 $\mu g/m^3$; the maximum exhaust face concentration was 176 $\mu g/m^3$. The concentration patterns for both species appear essentially random; they do not show the same characteristic concentration pattern at the exhaust and intake faces as the other measured parameters.

4. Isocyanates

The isocyanate method yields concentration data for MDI, TDI, and HDI. HDI, a component of the polyurethane topcoat, was detected during topcoat application. The other isocyanate compounds were neither detected nor listed in the MSDSs. Isocyanate Tests 1 through 4 were conducted during topcoat application; Test 5 was conducted during primer painting as a background check.

Figures 45 through 48 show the concentrations of HDI measured at the intake and exhaust faces during isocyanate Tests 1 through 4. All measurements less than 4.5 $\mu g/m^3$ correspond to one-half the MDL, which varied from test to test due to different collection times. HDI was not detected in any Test 5 samples.

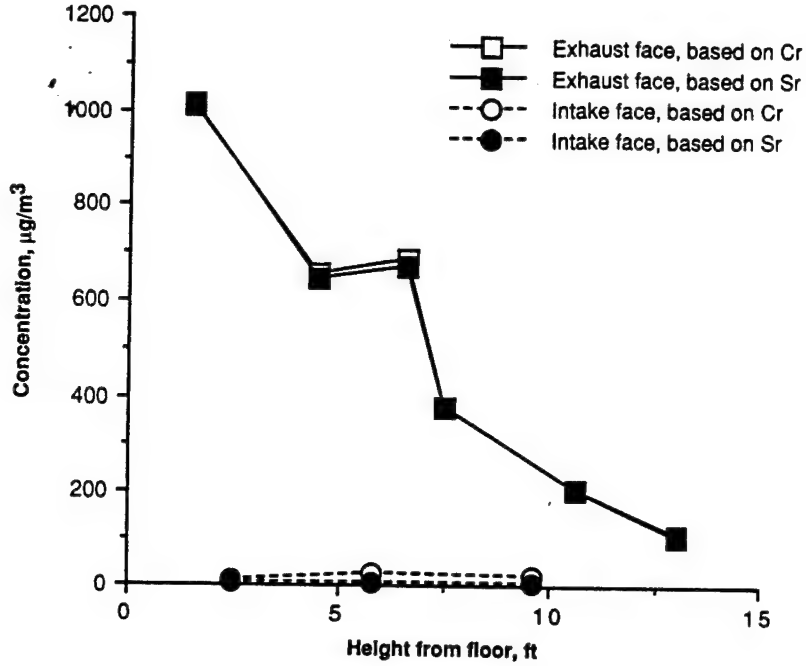


Figure 30. Concentrations of Strontium Chromate Measured at the Intake and Exhaust Faces—Test 1.

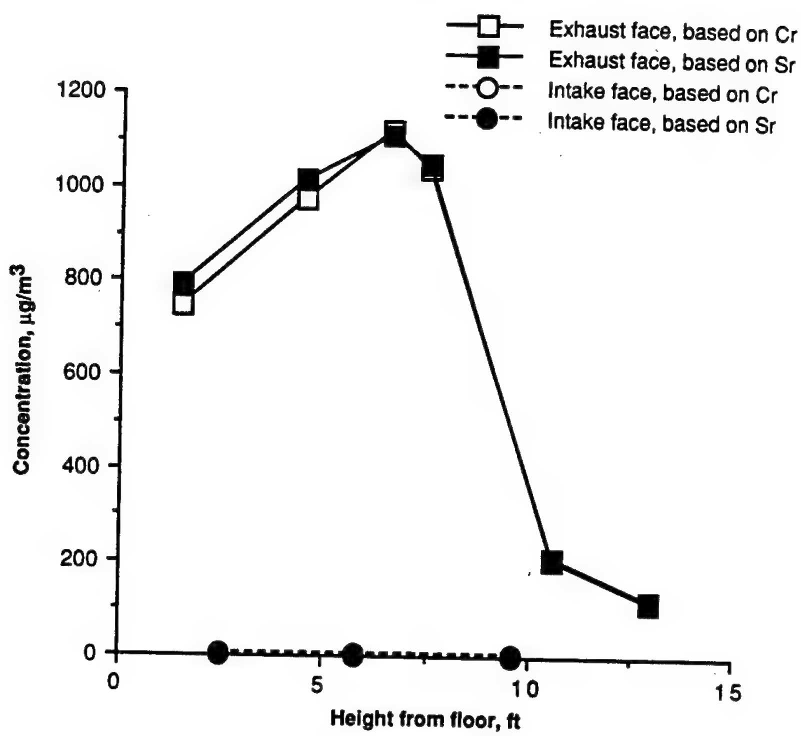


Figure 31. Concentrations of Strontium Chromate Measured at the Intake and Exhaust Faces—Test 2.

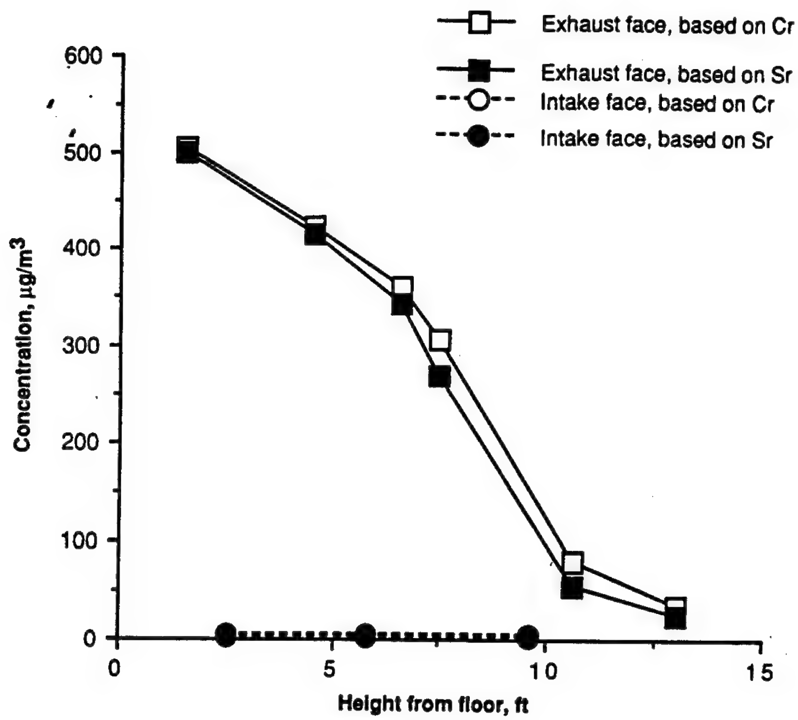


Figure 32. Concentrations of Strontium Chromate Measured at the Intake and Exhaust Faces—Test 3.

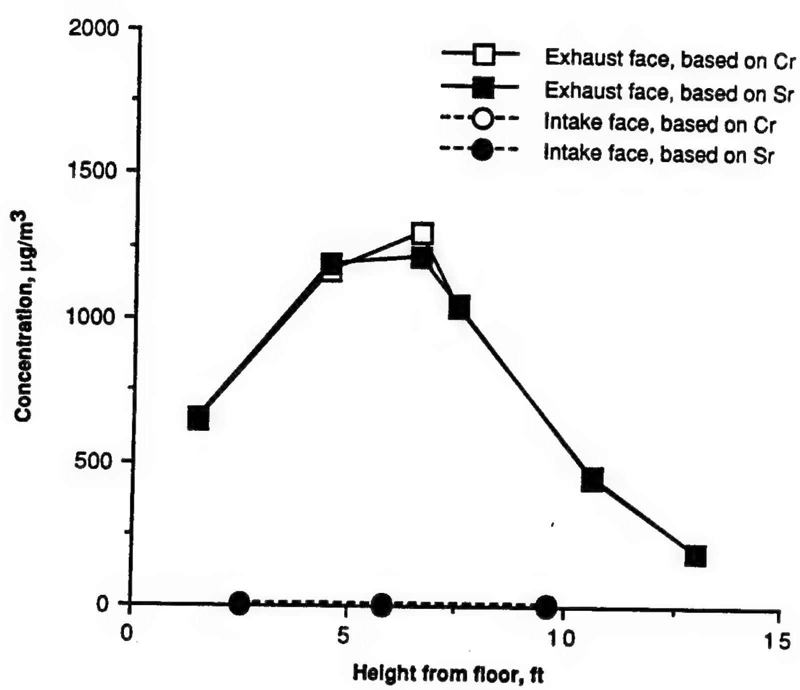


Figure 33. Concentrations of Strontium Chromate Measured at the Intake and Exhaust Faces—Test 4.

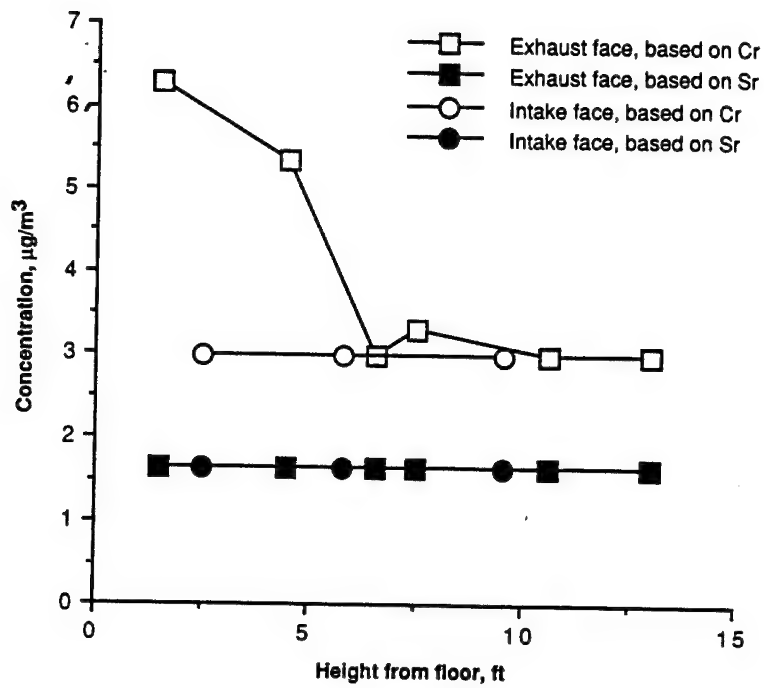


Figure 34. Concentrations of Strontium Chromate Measured at the Intake and Exhaust Faces—Test 5.

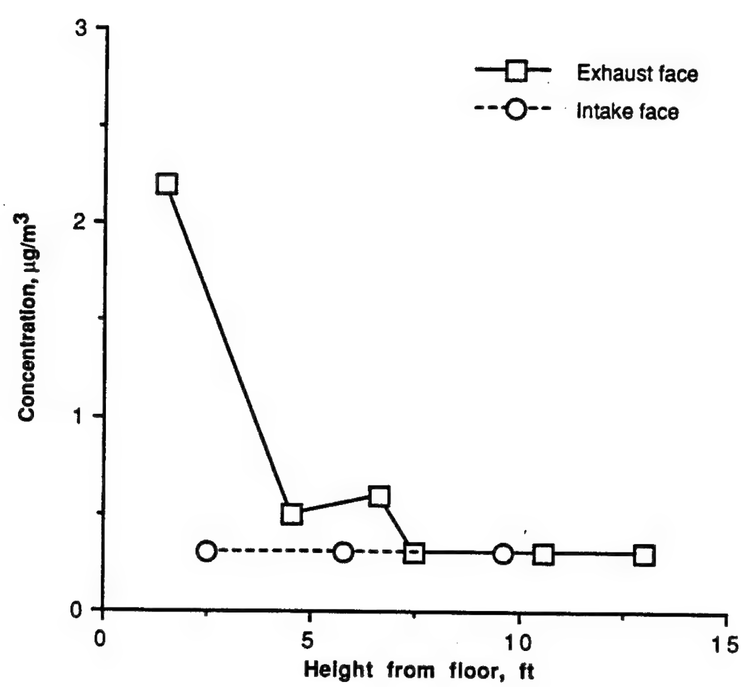


Figure 35. Concentrations of Lead at the Intake and Exhaust Faces—Test 1.

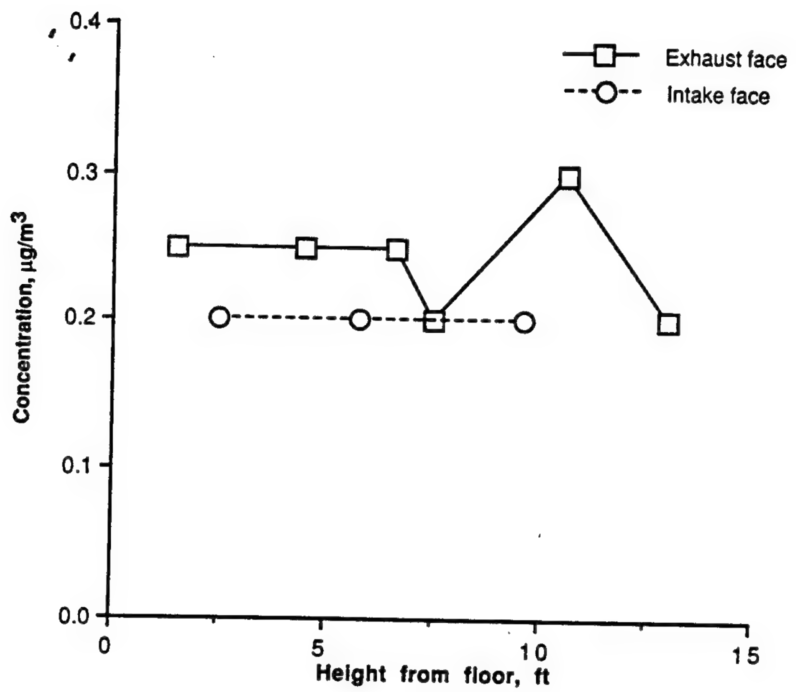


Figure 36. Concentrations of Lead at the Intake and Exhaust Faces—Test 2.

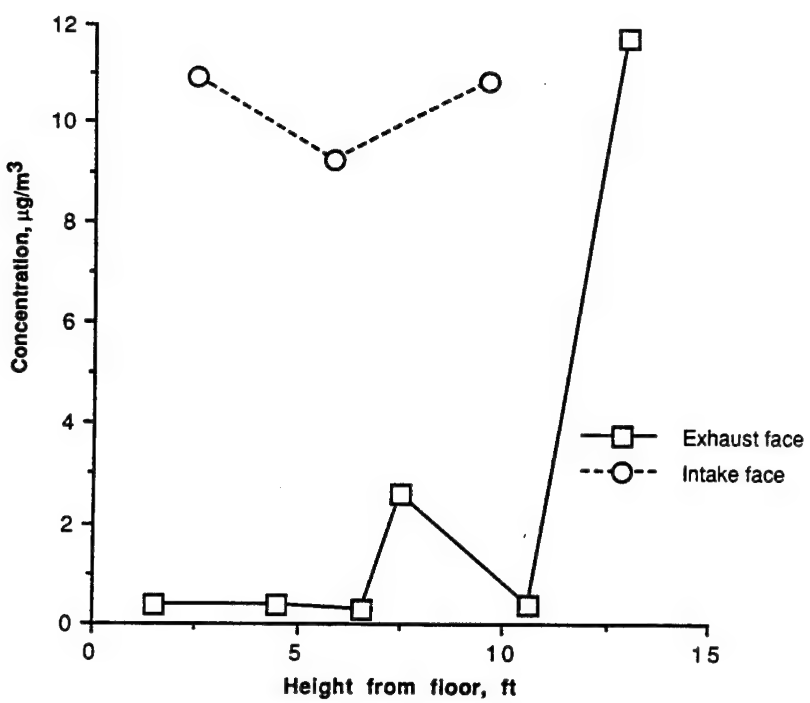


Figure 37. Concentrations of Lead at the Intake and Exhaust Faces—Test 3.

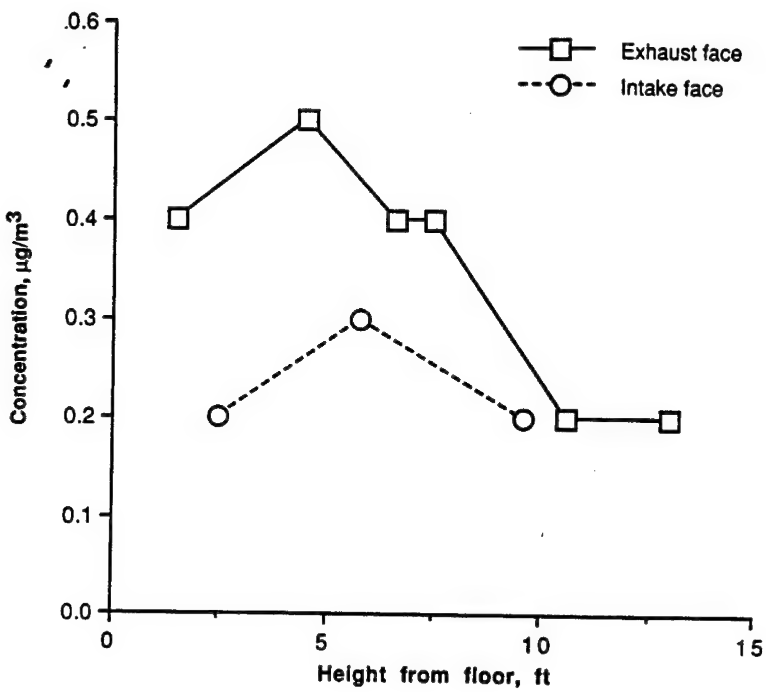


Figure 38. Concentrations of Lead at the Intake and Exhaust Faces—Test 4.

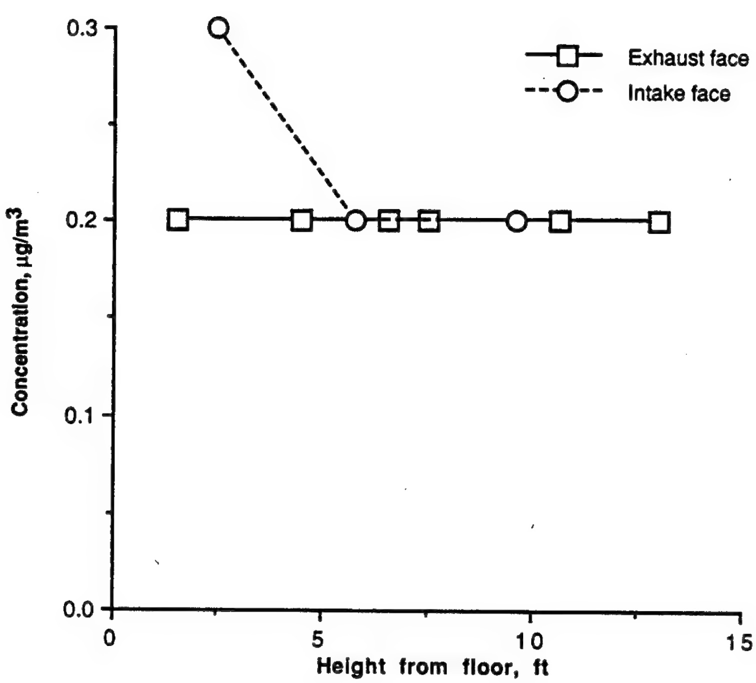


Figure 39. Concentrations of Lead at the Intake and Exhaust Faces—Test 5.

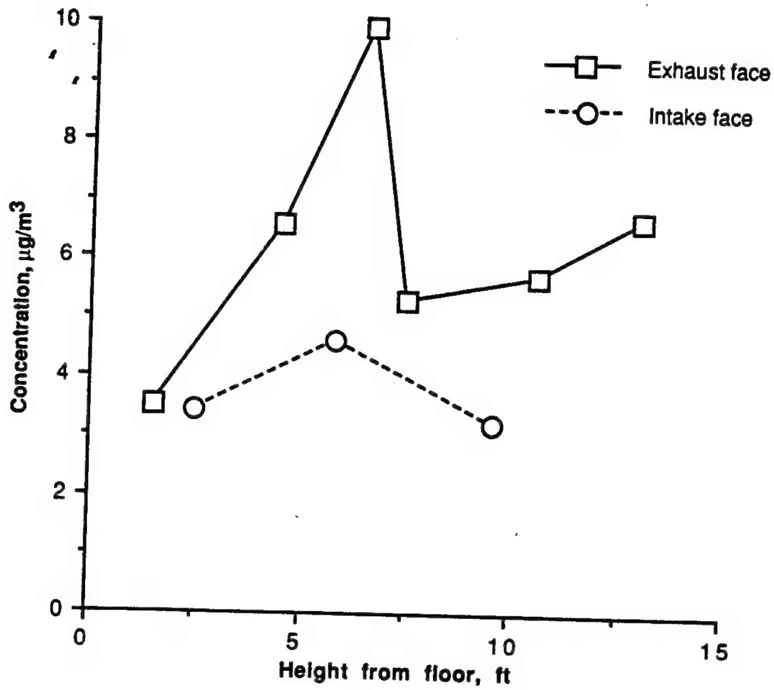


Figure 40. Concentrations of Zinc at the Intake and Exhaust Faces—Test 1.

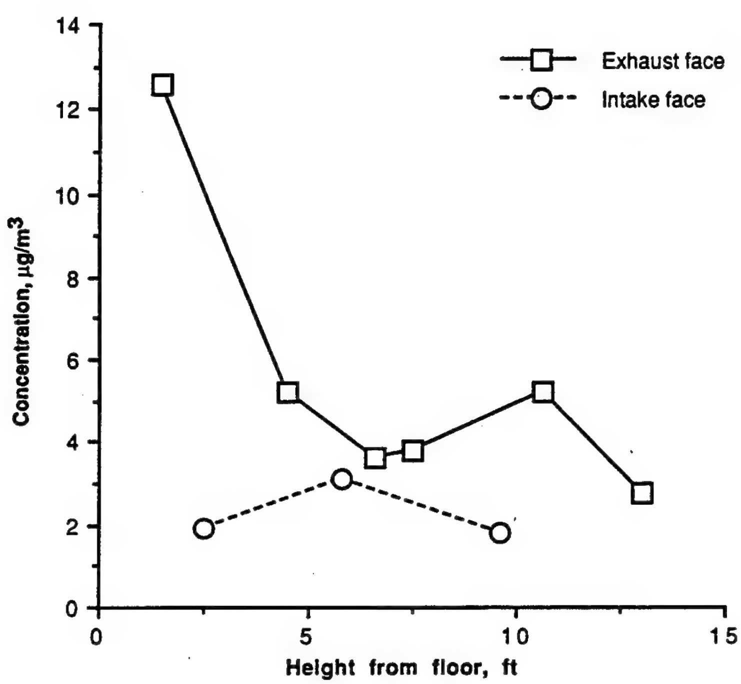


Figure 41. Concentrations of Zinc at the Intake and Exhaust Faces—Test 2.

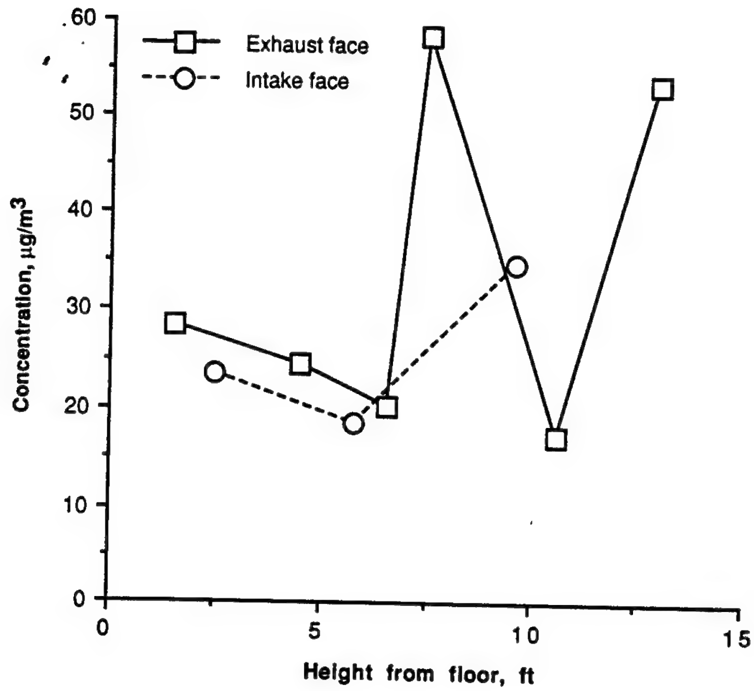


Figure 42. Concentrations of Zinc at the Intake and Exhaust Faces—Test 3.

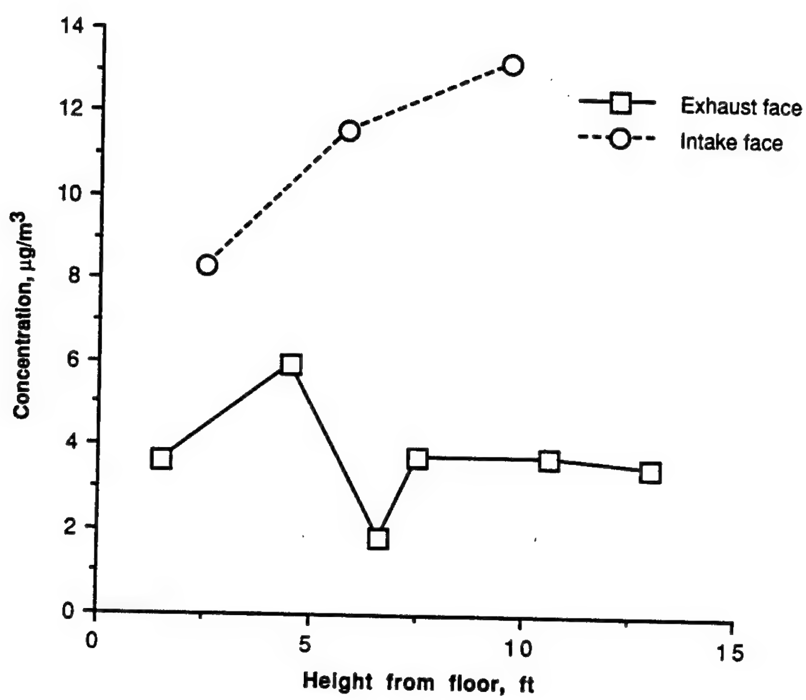


Figure 43. Concentrations of Zinc at the Intake and Exhaust Faces—Test 4.

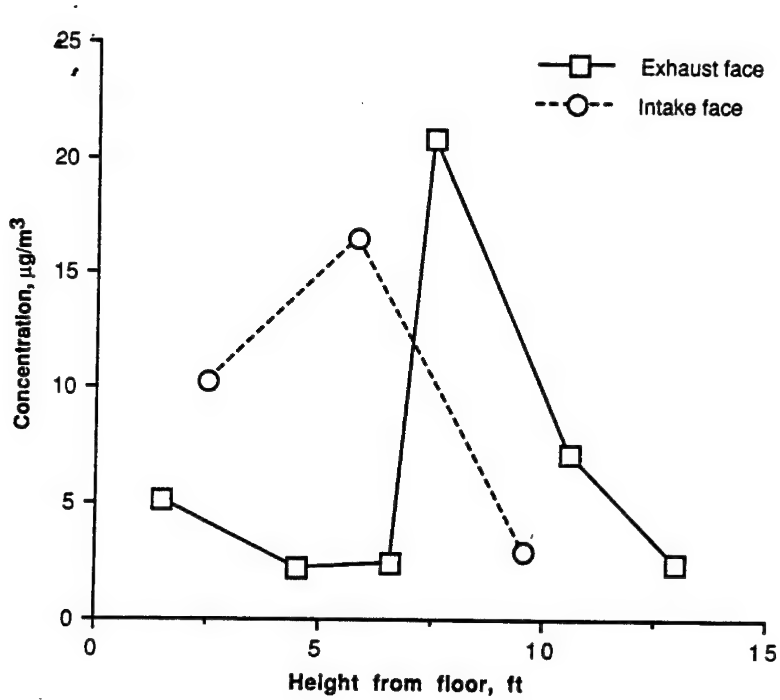


Figure 44. Concentrations of Zinc at the Intake and Exhaust Faces—Test 5.

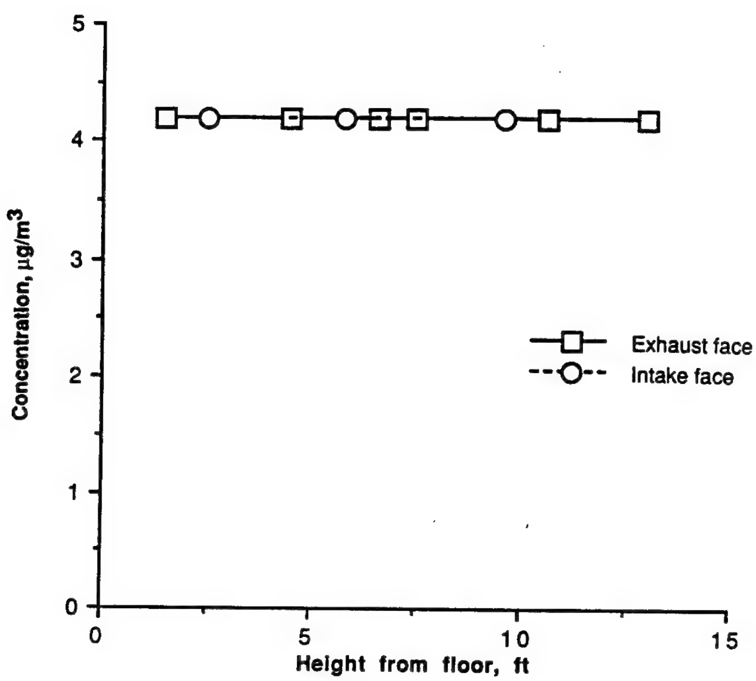


Figure 45. Concentrations of HDI Measured at the Intake and Exhaust Faces—Test 1.

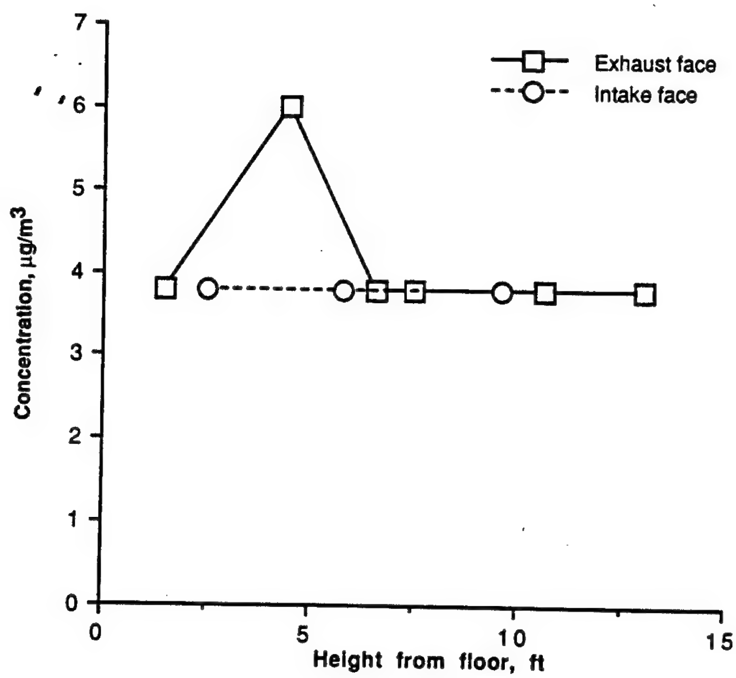


Figure 46. Concentrations of HDI Measured at the Intake and Exhaust Faces—Test 2.

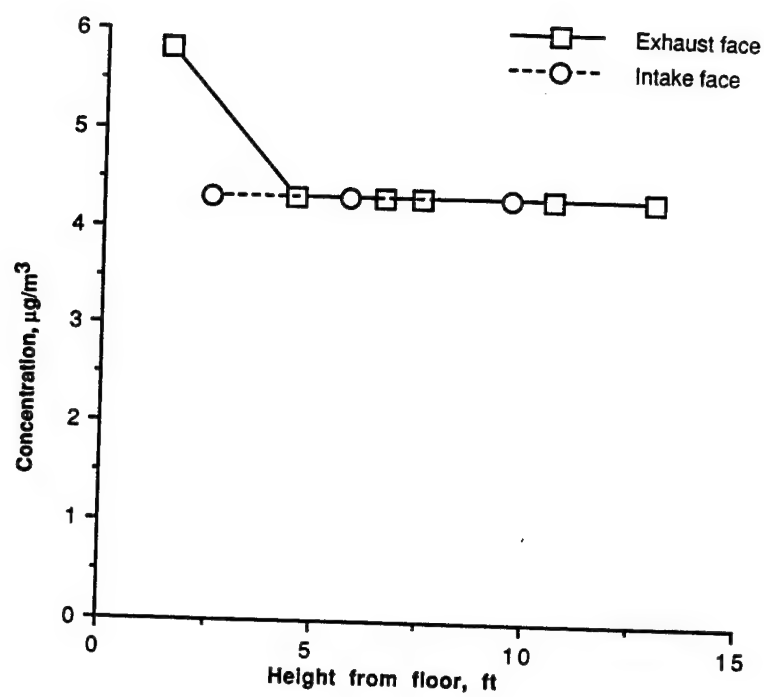


Figure 47. Concentrations of HDI Measured at the Intake and Exhaust Faces—Test 3.

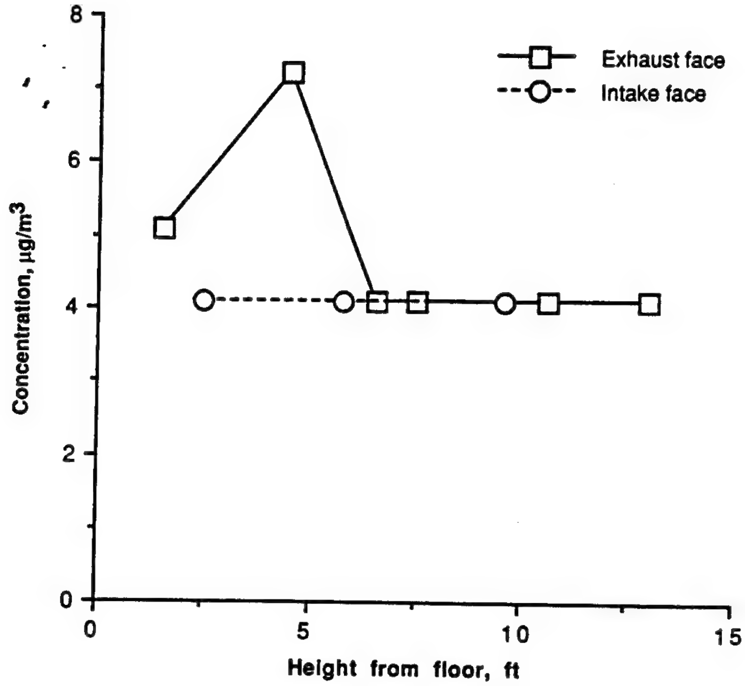


Figure 48. Concentrations of HDI Measured at the Intake and Exhaust Faces—Test 4.

F. RESULTS OF DUCT MEASUREMENTS

The duct measurement results are described below for both the split-flow and the combined split-flow/recirculating ventilation tests. Spreadsheets containing the reduced data are presented in Volume II, Appendix G. Each compound not detected is assumed to be present at one-half the MDL.

1. Organic Compounds

Measurements of organics in the two ducts were performed throughout the test program, during all split-flow and combined split-flow/recirculating ventilation tests.

a. Integrated Sampling

Integrated results for individual organic species from the NIOSH Method 1300 tests are provided in Volume II, Appendix G, along with sampling times and volumes. Table 19 lists the average concentration of total measured organics, which consisted primarily of MEK, MIBK, toluene, and butyl acetate.

The results of organic Tests 1 through 4 in split-flow/recirculating ventilation mode indicate that the average total organic concentration exiting through the split-flow duct (lower plenum) was greater than the concentration exiting the recirculation duct (upper plenum), confirming the top-to-bottom concentration gradient. During Tests 5 and 6, and split-flow Test 1, the average concentration in the split-flow duct was less than or equal to the concentration measured in the recirculation duct. In these three cases, topcoat paint was applied to objects

TABLE 19. AVERAGE CONCENTRATIONS OF TOTAL ORGANIC SPECIES MEASURED IN THE SPLIT-FLOW AND RECIRCULATION DUCTS USING NIOSH METHOD 1300.

Test	Average Organics Concentration (mg/m^3)	
	Split-flow Duct	Recirculation Duct
Split-flow/Recirculating Ventilation		
Organics Test 1	12	3.5
Organics Test 2	15	6.8
Organics Test 3	41	31
Organics Test 4	8.4	2.5
Organics Test 5	13	20
Organics Test 6	27	27
Split-flow Ventilation		
Organics Test 1	5.0	5.2

with heights of 8.5 feet, representing 60 percent of the total booth height. However, in every instance, the concentrations remained significantly lower than the computed STEL of 350 ppm for a mixture of paint components.

b. Continuous Emission Monitoring Results

CEM was conducted in both the split-flow duct and the recirculation duct. Two CEM methods were employed, BAAQMD Method ST-7 and EPA Method 25A.

BAAQMD Method ST-7 is not reliable when background CO_2 constitutes more than 85 percent, on a molar basis, of the total carbon in a sample. Because the TOC concentration measured in the ducts averaged between 10 and 40 ppm, the background CO_2, typically 370 to 400 ppm, averaged 85 to 98 percent of the total sample. The method also indicates that the minimum sensitivity of the detector is 2 percent of full scale; measured TOC ranged from 1 to 500 ppm, corresponding to less than 1 percent up to 30 percent of full scale.

Due to the high background CO_2 and the corresponding low signal-to-noise ratio observed during Method ST-7 testing, EPA Method 25A provided the more reliable data in this test program.

Figures 49 and 50 present representative outputs from Method 25A for the split-flow/recirculating ventilation tests. Figure 49 compares Method 25A results for the split-flow and recirculation ducts during one of the solvent-based topcoat painting tests. Figure 50 compares split-flow and recirculation duct concentrations during primer painting. Both figures show an emission peak corresponding to the painter's cleaning the paint spray gun with MEK. Comparing the two figures shows that polyurethane topcoat has a higher VOC content than the epoxy primer. This is consistent with the information reported in the respective MSDSs.

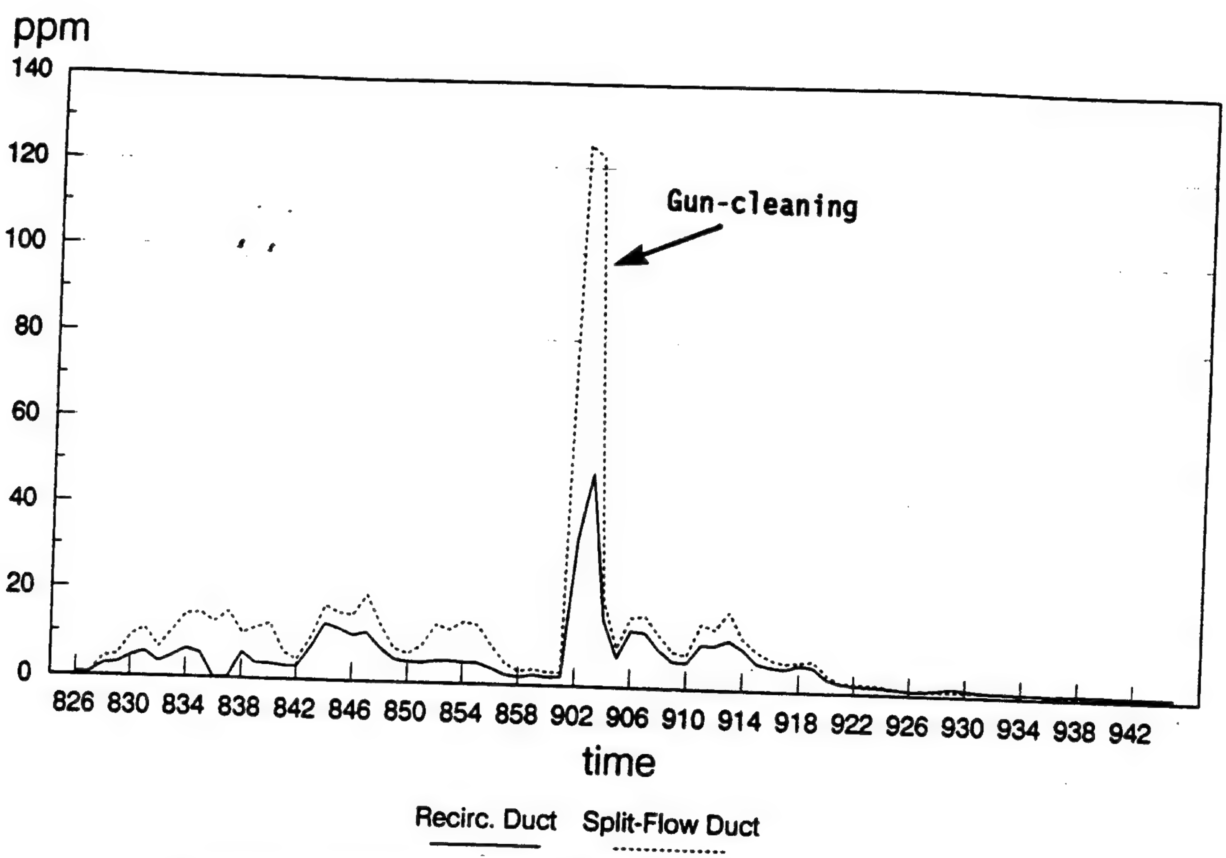


Figure 49. Representative Results from Continuous Emission Monitoring by EPA Method 25A—Topcoat Painting.

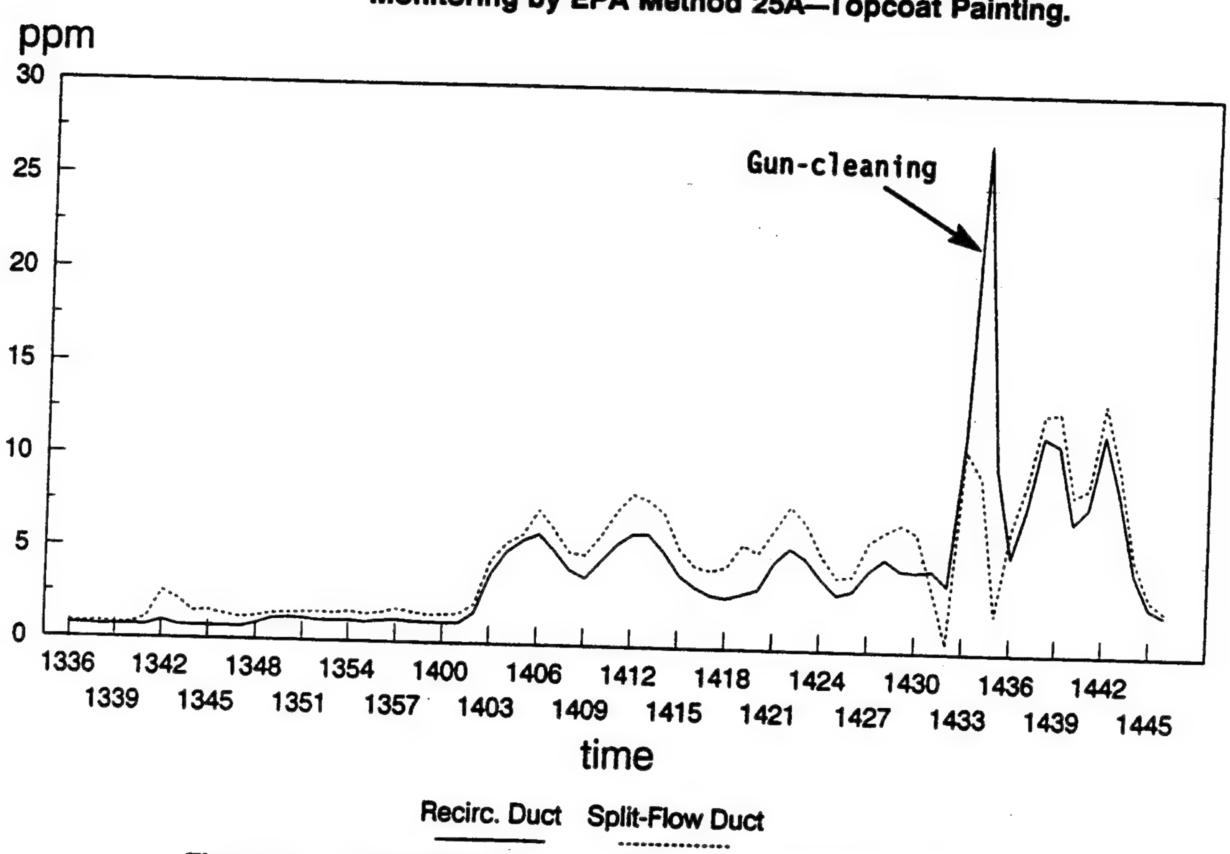


Figure 50. Representative Results from Continuous Emission Monitoring by EPA Method 25A—Primer Painting.

Figures 49 and 50 also indicate that the average concentration in both the recirculation and split-flow ducts is far below the pre-set booth concentration limit of 350 ppm. This is reaffirmed from the feedback FID results for the booth intake (site F, Figure 14).

The concentration of organics in the intake air was monitored using Method 25A downstream of the fresh air intake point. The FID used in this method was connected to the feedback control loop, a necessary condition required by HQ AFLC/SGBE to ensure against possible overexposure from organics in the recirculated air. Data recovered from the feedback FID indicate that the test conditions did not exceed safety standards.

Figure 51 is a sample strip chart indicating typical Method 25A results for split-flow ventilation (*i.e.*, no recirculation). In this test, both epoxy primer and polyurethane topcoat were applied, and the paint spray gun cleaning technique was different from that used during the split-flow/recirculating ventilation tests.

The practice of solvent recovery during paint spray gun cleaning significantly affected the solvent concentrations observed in the ducts. In Figures 49 and 50, a distinct VOC peak appears during the gun-cleaning process because the painter followed the common practice of discharging the solvent directly into the air. In the test represented by Figure 51, the gun-cleaning occurred at about 12:06 p.m. No gun-cleaning peak appears at that time point in Figure 51 because the painter filled the gun with MEK and sprayed it directly into a solvent waste container in the booth. Adopting the simple practice of discharging gun-cleaning VOCs into a recovery container would cost only the price of disposal of the solvents recovered, and would decrease the total VOC emissions from the installation by about 1 pound per shift worked by each painter.

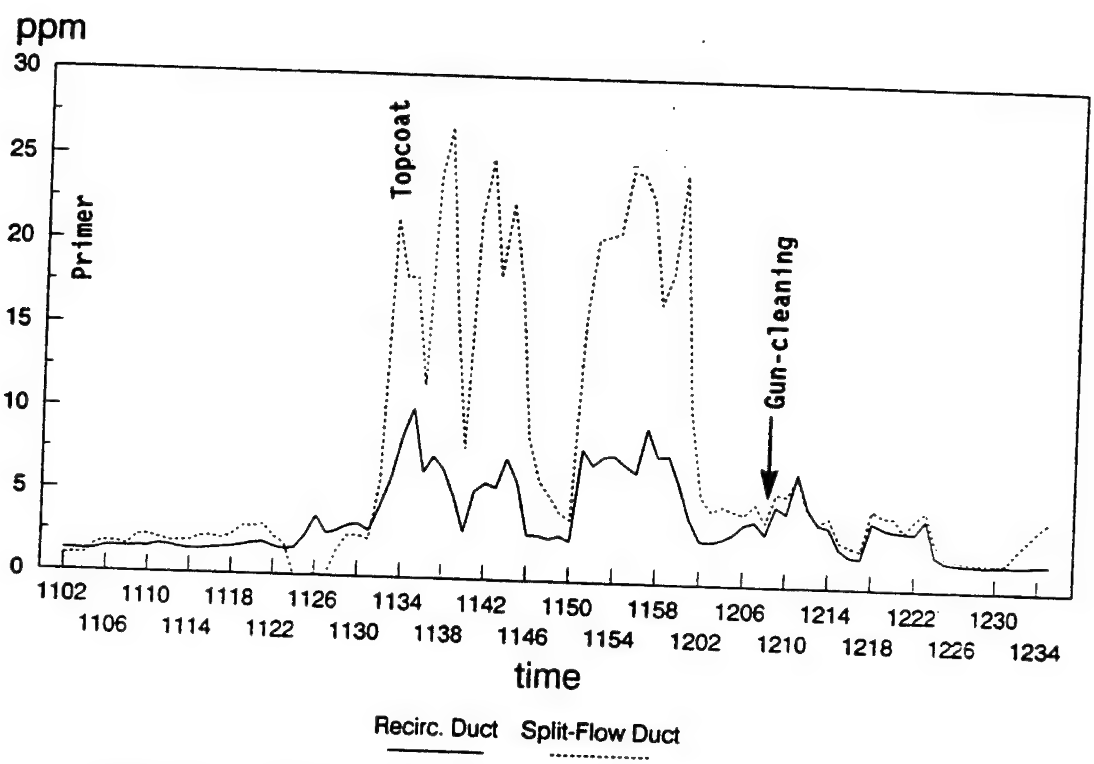


Figure 51. Representative Results from Continuous Emission Monitoring by EPA Method 25A—Split-flow Test.

c. Solvent Mass Balance Results

A mass balance was performed for every sampling event. BAAQMD Method ST-7 and EPA Method 25A results, and the paint MSDS information, were used to calculate the mass of VOCs released to the atmosphere during painting. The mass of VOCs was converted into an equivalent mass of carbon or propane to allow direct comparisons to the Method ST-7 and Method 25A results.

The mass balance results are presented in Table 20. The entire drying cycle typically was not measured; therefore, the solvent mass measured in the split-flow duct was less than the solvent mass released during painting. However, the results indicate that, during the test period, an average of 70 to 80 percent of the VOCs released from the painting operations were exhausted to the split-flow duct during split-flow/recirculating ventilation. Thus, in this mode, 70 to 80 percent of the VOCs would be discharged to a control device. In addition, if the object remains in the booth until dry, the percentage of VOCs captured and discharged to the VOC control device would approach 100 percent.

2. Particulate

Table 21 compares the concentrations of particulate measured from the split-flow and recirculation ducts during all tests. In 11 of the 19 tests, the particulate concentration measured in the split-flow duct was greater than that measured in the recirculation duct. The particulate measurements in the ducts were obtained downstream of the exhaust face particulate filters. Downstream of particulate collection, the split-flow duct and recirculation duct particulate concentrations would not be expected to differ significantly. Accordingly, the average concentration in both ducts over the 16 split-flow/recirculating ventilation tests was 3.3 mg/m^3.

The probe wash of several samples spilled in transport. In such cases, the analytical results were increased by the volume ratio of total initially collected solvent and the final analyzed solvent volume, to account for the lost sample.

3. Metals

Concentrations of metals in the split-flow and recirculation ducts are presented in Table 22. Concentrations of chromium in the ducts were greater than expected when based on the strontium results. In addition, Test 5 was conducted in the absence of primer containing strontium chromate; however, chromium was detected. Strontium was not detected, indicating that the source of chromium was not strontium chromate. Similarly, the concentrations of chromium, lead, and zinc were higher in the recirculation duct than in the split-flow duct. As with the exhaust and intake face metals results, these results may be due to the presence of zinc in the welding material (Reference 14), and the presence of chromium, lead, and zinc in the galvanized steel (Reference 15) that was used to construct the split-flow transition manifold. As the welding material is on the outside of the split-flow duct but on the inside of the recirculation duct, the recirculation duct would be expected to release more stray metal dust than the split-flow duct.

4. Isocyanates

Measurements of HDI were made in the two ducts. The results are tabulated in Table 23. The results indicate that isocyanates tend to exit from the lower portion of the exhaust plenum, confirming the concentration gradient phenomenon upon which split-flow ventilation is

TABLE 20. SOLVENT MASS BALANCE RESULTS.

Test	Mass of Carbon Released into Booth (paint use data) (g)	Mass of Carbon Measured in the Split-flow Duct		Percent of Solvents Released that are Accounted for	
		BAAQMD Method ST-7 (g)	EPA Method 25A (g)	BAAQMD Method ST-7	EPA Method 25A
Split-flow/Recirculating Ventilation					
Organics Test 2	460	65	399	14[a]	87
Organics Test 3	601	208	594	35	99
Organics Test 4	272	19	242	7[a]	89
Organics Test 5	862	631	555	73	64
Organics Test 6	588	9	498	2[a]	85
Particulate Test 1	416	466	379	112	91
Particulate Test 2	306	290	131	95	43
Particulate Test 3	355	224	131	63	37
Particulate Test 4[b]	150	61	31	41[b]	21[b]
Particulate Test 5	274	232	77	85	28
Isocyanates Test 1	579	447	487	77	84
Isocyanates Test 2	575	545	359	95	62
Isocyanates Test 3	326	315	243	96	74
Isocyanates Test 4	356	297	347	84	98
Isocyanates Test 5	101	2	72	2[a]	71
Metals Test 1	378	298	179	79	47
Metals Test 2	146	63	41	43	28
Metals Test 3	96	67	50	69	52
Metals Test 4[b]	306	262	91	86[b]	30[b]
Metals Test 5	765	834	669	109	88
Split-flow Ventilation					
Organics Test 1	616	334	323	54	52
Particulate Test 1	373	372	543	100	146
Particulate Test 2	333	387	426	116	128

[a]Method ST-7 equipment faulty.
[b]Due to power loss or electrical interference, booth converted to single-pass; invalid test.

TABLE 21. CONCENTRATIONS OF PARTICULATE MEASURED IN THE SPLIT-FLOW AND RECIRCULATION DUCTS.

Test	Split-flow Duct			Recirculation Duct		
	Filter (mg/m^3)	Probe Wash (mg/m^3)	Total (mg/m^3)	Filter (mg/m^3)	Probe Wash (mg/m^3)	Total (mg/m^3)
Split-flow/Recirculating Ventilation						
Organics Test 1	9.8	1.2	10.9	1.5	2.0	3.5
Organics Test 2	2.3	3.9	6.2	1.0	2.2	3.2
Organics Test 3	ND[a]	1.9	1.9	1.2	3.7 PC[b]	4.8
Organics Test 4	ND	6.2	6.2	0.5	14.0 PC	14.5
Particulate Test 1	0.4	1.8	2.2	0.6	1.4	2.0
Particulate Test 2	0.5	ND	0.5	0.9	1.6	2.4
Particulate Test 3	0.1	2.9	3.0	0.1	1.9	2.0
Isocyanates Test 1	ND	2.5	2.5	0.5	1.9 PC	2.4
Organics Test 5	ND	3.7	3.7	0.5	ND	0.5
Particulate Test 4	0.5	1.6	2.1	0.7	3.7	4.4
Isocyanates Test 2	1.4	1.4	2.8	0.7	ND	0.7
Isocyanates Test 3	0.9	0.1	1.1	1.3	1.3	2.7
Particulate Test 5	3.5	2.6	6.2	1.0	2.2	3.2
Isocyanates Test 4	0.6	1.2	1.8	1.2	2.1	3.3
Isocyanates Test 5	ND	ND	0.0	0.2	2.7	2.9
Organics Test 6	ND	1.4	1.4	0.64	0.02	0.66
Split-flow Ventilation						
Organics Test 1	ND	6.3	6.3	0.5	4.7 PC	5.2
Particulate Test 1	NA	13.7	13.7	2.3	0.8	3.1
Particulate Test 2	0.9	ND	0.9	N.A.[c]	2.0	2.0

[a]ND = Not detected. The final sample weight was equal to or less than the initial sample weight.
[b]PC = Paint chips observed in probe wash. Chips may have originated from sampling apparatus.
[c]N.A. = Not available. No final sample weight was obtained.

TABLE 22. CONCENTRATIONS OF METALS MEASURED IN THE SPLIT-FLOW AND RECIRCULATION DUCTS.

Test	Concentration ($\mu g/m^3$)							
	Lead		Zinc		Strontium		Chromium	
	Split-flow Duct	Recirc. Duct	Split-flow Duct	Recirc. Duct	Split-flow Duct	Recirc. Duct	Split-flow Duct	Recirc. Duct
Metals Test 1	<0.3[a]	1.8	29	96	14	11	23	63
Metals Test 2	<0.2	<0.2	77	47	12	9.3	27	35
Metals Test 3	<0.2	13	11	114	5.5	5.4	8.0	84
Metals Test 4	<0.2	<0.2	19	43	12	11	16	33
Metals Test 5	<0.2	4.0	37	40	0.7	0.5	12	25

[a]< = Compound not detected. Values listed are one-half the MDL.

TABLE 23. CONCENTRATIONS OF HDI IN THE SPLIT-FLOW AND RECIRCULATION DUCTS.

Test	HDI Concentration ($\mu g/m^3$)	
	Split-flow Duct	Recirculation Duct
Isocyanates Test 1	17	17
Isocyanates Test 2	33	<3.3[a]
Isocyanates Test 3	9.4	<3.6
Isocyanates Test 4	19	<3.8
Isocyanates Test 5	<4.0	<3.9

[a]< = Compound not detected. Values listed are one-half the MDL.

based. Test 1, in which the concentrations in the two ducts were essentially equal, was conducted during the application of polyurethane topcoat to the 7.5-foot-high comfort pallet. The average concentration of 17 $\mu g/m^3$ is less than half of the 40 $\mu g/m^3$ PEL for HDI.

G. RESULTS OF MEASUREMENTS AT THE PAINTER

The measurement results in the vicinity of the painter are described below for both the split-flow and the combined split-flow/recirculating ventilation tests. Spreadsheets containing the reduced data are presented in Volume II, Appendix G. Each compound not detected is assumed to be present at one-half the MDL.

1. Organic Compounds

The organic concentrations measured outside and inside the painter's respirator hood are presented in Tables 24 and 25, respectively. The results affirm the prediction that the mode of ventilation makes a relatively minor contribution to the net concentration of toxicants in the vicinity of the painter.

2. Particulate

Table 26 presents the concentrations of particulate measured in the vicinity of the painter. Particulate was not detected inside the painter's respirator in any of the tests. The results outside the painter's respirator ranged from 0.5 to 41 mg/m^3.

3. Metals

The concentrations of metals detected outside and inside the painter's respirator are presented in Tables 27 and 28, respectively. The concentrations observed outside the respirator were significantly greater than that detected inside it. Metals detected inside the respirator hood were likely due to leakage into the hood, which is loose-fitting.

4. Isocyanates

The concentrations of HDI measured at the painter, outside and inside the painter's respirator, are presented in Table 29. All isocyanate tests were conducted in the split-flow/recirculating ventilation mode. Test 1, in which the HDI concentration outside the respirator was 280 $\mu g/m^3$, occurred during the application of topcoat in the inside of the comfort pallet. This concentration was caused by the airflow restrictions in the enclosed space, and was unrelated to the mode of booth ventilation.

TABLE 24. CONCENTRATIONS OF ORGANICS OUTSIDE THE PAINTER'S RESPIRATOR.

Test	Concentration (mg/m^3)						
	MEK	MIBK	Toluene	Ethyl-benzene	Butyl Acetate	Xylenes	Total
Split-flow/Recirculating Ventilation							
Organics Test 1	0.4	21.8	2.3	<0.1[a]	<0.1	0.2	25
Organics Test 2	11.5	6.9	3.8	<0.1	1.1	<0.3	24
Organics Test 3	2.7	4.7	<0.1	<0.12	1.2	<0.35	9.2
Organics Test 4	<0.2	<0.17	<0.2	<0.21	<0.2	<0.6	<1.6
Organics Test 5	8.6	62.7	12	1.1	17.3	1.7	103
Organics Test 6	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Split-flow Ventilation							
Organics Test 1	0.4	3.2	0.4	0.2	1.9	0.3	6.4

[a]< = Compound not detected. Values listed are one-half the MDL.
[b]The sample pump stopped and no sample was collected.

TABLE 25. CONCENTRATIONS OF ORGANICS INSIDE THE PAINTER'S RESPIRATOR.

Test	Concentration (mg/m^3)						
	MEK	MIBK	Toluene	Ethyl-benzene	Butyl Acetate	Xylenes	Total
Split-flow/Recirculating Ventilation							
Organics Test 1	<0.1[a]	<0.08	<0.09	<0.09	<0.09	<0.29	<0.7
Organics Test 2	0.2	<0.1	<0.1	<0.1	<0.1	<0.3	<0.9
Organics Test 3	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Organics Test 4	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Organics Test 5	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Organics Test 6	<0.09	1.7	5.9	<0.09	0.5	<0.29	8.6
Split-flow Ventilation							
Organics Test 1	<0.08	<0.07	0.5	0.2	0.5	<0.27	1.6

[a]< = Compound not detected. Values listed are one-half the MDL.
[b]The sample pump stopped and no sample was collected.

TABLE 26. PARTICULATE CONCENTRATIONS MEASURED IN THE VICINITY OF THE PAINTER.

Test	Particulate Concentration (mg/m^3)	
	Outside Respirator	Inside Respirator
Split-flow/Recirculating Ventilation		
Particulate Test 1	41	<0.40[a]
Particulate Test 2	0.9	<0.25
Particulate Test 3	13	<0.25
Particulate Test 4	14	<0.24
Particulate Test 5	0.5	<0.25
Split-flow Ventilation		
Particulate Test 1	<0.25	<0.25
Particulate Test 2	10	3.0

[a]< = Compound not detected. Values listed are one-half the MDL.

TABLE 27. CONCENTRATIONS OF METALS OUTSIDE THE PAINTER'S RESPIRATOR.

Test	Concentration ($\mu g/m^3$)			
	Lead	Zinc	Strontium	Chromium
Split-flow/Recirculating Ventilation				
Metals Test 1	<0.3[a]	4.6	380	267[b]
Metals Test 2	0.6	9.1	1,070	610
Metals Test 3	0.6	20	110	68
Metals Test 4	0.4	1.6	680	390
Metals Test 5	<0.19	3.2	5.0	3.5

[a]< = Compound not detected. Values listed are one-half the MDL.
[b]Average of 2 samples.

TABLE 28. CONCENTRATIONS OF METALS INSIDE THE PAINTER'S RESPIRATOR.

Test	Concentration ($\mu g/m^3$)			
	Lead	Zinc	Strontium	Chromium
Split-flow/Recirculating Ventilation				
Metals Test 1	<0.3[a]	3.4	50	54[b]
Metals Test 2	<0.2	2.0	41	24
Metals Test 3	<0.2	15	<0.8	6.8
Metals Test 4	<0.16	1.7	70	42
Metals Test 5	<0.19	2.9	<0.76	<0.76

[a]< = Compound not detected. Values listed are one-half the MDL.
[b]Average of 2 samples.

TABLE 29. CONCENTRATIONS OF HDI AT THE PAINTER'S BREATHING ZONE.

Test	Concentration of HDI ($\mu g/m^3$)	
	Outside Respirator	Inside Respirator
Split-flow/Recirculating Ventilation		
Isocyanates Test 1	280	3.4
Isocyanates Test 2	44	3.0
Isocyanates Test 3	17	3.3
Isocyanates Test 4	16	<0.41[a]
Isocyanates Test 5	3.6	3.6

[a]< = Compound not detected. Value listed is one-half the MDL.

SECTION VI

INDUSTRIAL HYGIENE EVALUATION

The following section was prepared by Clayton Environmental Consultants, Inc. (Clayton) and contains discussion of industrial hygiene issues associated with recirculation of paint booth air.

A. OBJECTIVE

The objective of this program was to demonstrate that split-flow and recirculating ventilation, individually and in combination, are safe and cost-effective methods to reduce paint spray booth exhaust flow rates and thus lower the cost of controlling VOC emissions. This demonstration was conducted at Paint Spray Booth 2, Building 845, Travis AFB, in Fairfield, California. The study was designed to show that paint booth air could be recirculated without creating a safety hazard or an atmosphere at the intake face exceeding the Air Force's standards for airborne contaminants in a worker's breathing zone.

B. APPROACH

To achieve the project objective, two test series were conducted: (1) baseline, and (2) combined split-flow/recirculating ventilation. The baseline test series characterized the distribution of toxic pollutants at the exhaust face and in the exhaust duct of Booth No. 2. These results were used to locate the split position and the recirculation rate for the split-flow/recirculating ventilation test series. These data and the test plan for the second set of tests were reviewed by HQ AFLC/SGBE before approval was given to proceed with the recirculation tests.

Prior to the second test series, the duct work in Booth No. 2 was reconfigured to separate exhaust streams from the top and bottom of the booth (split-flow) and to return the upper exhaust stream to the intake plenum for recirculation through the booth. The split-flow recirculating ventilation test series demonstrated the feasibility of flow reduction to enhance the economics of VOC emissions control. During this test series, several split-flow tests were also conducted to verify that split-flow ventilation by itself improves the economics of VOC emissions control, and that the ventilation system was designed correctly. The results of the split-flow/recirculating ventilation and split-flow tests were also used to evaluate the impact of recirculation on pollutant concentration profiles in the booth.

For the baseline and split-flow/recirculating ventilation test series, comprehensive sampling and analysis matrices were developed. Each test matrix included sampling in the ventilation ducts and in the booth at the exhaust face to measure concentrations of VOCs, particulate, metals, and isocyanates. In-booth sampling identified constituent concentration profiles at the exhaust face during painting as well as concentrations in the vicinity of the painter. Duct sampling yielded constituent concentrations in the ventilation streams. Such engineering parameters as temperature, pressure, and flow rate were also measured.

The purpose of the test program was to determine the effectiveness of the split-flow and recirculation modifications in typical Air Force painting operations; it was a proof-of-concept study only. It is recognized that the concentration gradients that occur during painting depend on both the flow parameters of the ventilation system and the size and orientation of the object painted.

In general, small workpieces (less than 5 feet high) are painted at the Air Force facility targeted for conversion. Previous studies have demonstrated that, under these conditions, favorable vertical concentration gradients occur (Reference 4).

In this study, the painter typically painted for 2 hours during each 8-hour workday. Therefore, the concentrations the painter was exposed to over the entire workday are partial sums of the concentrations in the booth for 2 hours of each day and background concentration in the workplace for the remaining 6 hours of each workday. This background concentration was assumed to be zero. Because painting requires significant preparation time, this estimate of 2 hours of painting time per day, or 10 hours of painting time per week, is considered typical.

Each activity conducted at Travis AFB depended upon prior approval. Details of proposed activities were sent to Travis AFB and the base Environmental Management (EM) Office, to expedite approval by the respective fire, safety, and bioenvironmental engineering authorities before commencement of booth testing or modification activities. In addition, the test plan was reviewed and approved by HQ AFLC/SGBE.

The strategy for evaluating the effects of recirculation on worker exposure is based on a comparison of air sampling data outside of the hood and the assigned respirator protection factor to determine if the calculated TWA exposure is within the applicable exposure standard.

C. STANDARDS AND GUIDELINES

In the United States, two organizations publish exposure limits for airborne chemicals. The first is the federal Occupational Safety and Health Administration (OSHA). The OSHA exposure limits are called Permissible Exposure Limits (PELs) and are codified into Department of Labor regulations in Title 29 of the Code of Federal Regulations (CFR), Part 1910.1000. These are the exposure limits that are enforceable by OSHA during inspections of the workplace. The second organization is the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH publishes recommended exposure limits known as Threshold Limit Values (TLVs). These limits are intended to be used as guidelines for good practice. Both OSHA standards (PELs) and ACGIH guidelines (TLVs) for the chemicals involved in this study are listed in Table 30. The exposure limits referenced are 8-hour time-weighted average (TWA) concentrations. Other limits such as Short-Term Exposure (STEL) or Ceiling (C) limits are not addressed because of limitations in the sampling data. Since the PEL and the TLV for the same chemical can be different, the Air Force/SG policy is to use the more stringent of the two values when assessing airborne chemical exposures to Air Force personnel.

In January 1989, OSHA revised the 1910.1000 Air Contaminants standards, which resulted in lower limits for some chemicals and newly established limits for others. However, on July 7, 1992, the U.S. Court of Appeals for the 11th Circuit vacated and remanded OSHA's generic rulemaking. The Department of Justice has decided not to fight the ruling. Had the revised standards remained in effect, exposure limits for several of the target chemicals of this study would have been lowered. Those proposed limits are also included in Table 30.

The ACGIH updates TLVs each year. Table 30 lists the 1990 TLVs and the 1993 TLVs for target compounds. Three differences between 1990 and 1993 TLVs relate to this discussion:

- TLV (TWA) for toluene changes from 377 to 188 mg/m^3

TABLE 30. OSHA PELs AND ACGIH TLVs FOR TARGET COMPOUNDS (8-HOUR TWA).

Compound	OSHA PEL (1971) (mg/m^3)	OSHA PEL (Proposed) (mg/m^3)	OSHA PEL (1990) (mg/m^3)	ACGIH TLV (1993) (mg/m^3)
Zinc (As ZnO)	15	10	10	10
Lead[a]	0.05	0.05	0.15	0.15 (0.05)[b]
Chromium (VI compounds as Cr)	0.1 (ceiling)	0.1 (ceiling)	0.05	0.05
Strontium chromate (As Cr)	None	None	None	0.0005
HDI	None	None	0.034	0.034
MEK	590	590	590	590
MIBK	410	205	205	205
Toluene	754	375	377	188
n-Butyl acetate	710	710	713	713 (95)[b]
Ethylbenzene	435	435	434	434
Xylenes	435	435	434	434

[a]As defined in 29 CFR 1910.1025.
[b]Intended change.

- TLV (TWA) for *n*-butyl acetate is listed as an "intended change" to 95 mg/m^3
- TLV (TWA) for strontium chromate was adopted in 1992

When evaluating exposures to mixtures of chemicals, both OSHA and the ACGIH provide guidance for assessing exposures. When dealing with these mixtures, the combined effect, rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, the effects of the different hazards should be considered as additive. If the result of the following equation exceeds unity, then the exposure limit of the mixture should be considered as being exceeded.

$$E_m = \sum \left(\frac{C_1}{L_1} + \frac{C_2}{L_2} \ldots + \frac{C_i}{L_i} \right) \qquad (18)$$

where:

E_m = The exposure index for the mixture

C_i = The 8-hour TWA concentration of contaminant i
L_i = The PEL or TLV for substance i

TWA concentrations are based on monitoring during an 8-hour work shift.

The above equation should be used to assess exposures to mixtures of chemicals only when there is good reason to believe that the chief effects of the different chemicals are in fact additive. Chemicals having dissimilar toxicologic effects or having effects considered synergistic when presented in combination should be evaluated separately.

Chemical exposures encountered during the paint spray operations conducted during this study can be classified by potential toxicity into three categories:

- Organic solvents
- Metals
- Isocyanates

Because these classes of chemicals have dissimilar toxicologic effects, exposure indices (E_m) were calculated for each category and compared to the criterion exposure index of 0.25 arbitrarily established by HQ AFLC/SGBE for this study.

The specific chemicals are listed in the tables in Volume II, Appendices F and G.

D. PERSONAL PROTECTIVE EQUIPMENT

As outlined by Acurex Environmental, personal protective equipment worn by the painter during both the baseline and postmodification sampling efforts consisted of Tyvek® coveralls, gloves, and a hood-type airline respirator (Type C Continuous Flow). The respirator was Model 20-T, manufactured by the E.D. Bullard Company. The air compressor supplying the hood was a Model ADP-A-C, also provided by Bullard. Performance data from Bullard indicate that the compressor can deliver up to 11.7 scfm at approximately 11 psig using a V-20-100ST hose with 1/2-inch QD couplers. The assigned protection factor of this type of respirator is 1,000[1] based on a minimum air flow through the hood of 6 cfm. As indicated by Acurex Environmental, the painter adjusted the equipment according to his normal routine, and hood air flow rate and hose pressures were not monitored or recorded.

When interpreting the air sampling data sets for outside (over) and inside (under) the respirator hood, it is important to note that the Model 20-T hood, according to Bullard, is not equipped with an inner bib. The persons responsible for sample collection have reported to Clayton that the sampling medium for under-hood breathing zone collection was attached to the shoulder near the collar bone. These conditions make it difficult to assume that the air samples collected under the respirator hood are representative of the painter's breathing zone exposure.

Bullard informed Clayton that the use of a Model 20-TIC hood is typically recommended for use during spray painting. This model has an inner bib. The use of a hood without an inner

[1] Refer to ANSI Standard for Respiratory Protection (Z88.2-1992).

bib could compromise the respirator's protection ability by allowing paint mist and other contaminants to be introduced under the hood during head movement.

E. SAMPLING MATRIX AND METHODS

Samples to represent breathing zone concentrations were collected both inside and outside of the painter's hood during baseline, split-flow, and combined split-flow/recirculating ventilation tests. The number of sample sets is summarized in Table 31. Each sample set represents a pair of inside/outside respirator samples.

Samples were collected by Acurex Environmental's staff. In describing the sampling geometry, Acurex Environmental stated that, to accomplish painter breathing zone sampling, they attached two pumps to the painter. Sampling medium was attached to the shoulder, with one sampler under the hood and the other outside the hood. Based on information provided to Clayton, supplied-air hoods without inner bibs were used during the collection of all sample sets. The issue of inner bibs on the supplied-air hoods is discussed in the previous paragraph.

Detailed discussions of the sampling methods for baseline and postmodification testing are included in Section IV (B) and in Section V (B).

F. RESULTS OF SAMPLE SET ANALYSIS

Because of the suspect nature of the breathing zone samples collected under the supplied-air hood, Clayton will not utilize the data for those samples during the analysis of the effects of recirculation on the exposure hazard to the painter. This decision can be supported by the fact that review of the data from several sample sets of organic vapor and metals analyses reveals respirator PFs of less than 10. This is highly suspect since the assigned PF for supplied-air continuous-flow hood-type respirators equipped with inner bibs is 1,000, and in most cases actual PFs are even higher.

The objective of analysis of the air sampling data is to demonstrate that painting under recirculating ventilation conditions does not exceed the criterion exposure index (E_m) value of 0.25 specified by HQ AFLC/SGBE.

Because the breathing zone air sampling data are suspect, the air sampling data collected outside the respirator hood will be used to calculate the E_m for each of the contaminant categories. As the data were collected outside the respirator hood, they represent the exposure

TABLE 31. AIR SAMPLING MATRIX.

Parameters	No. of Baseline Air Sample Sets	No. of Split-flow Air Sample Sets	No. of Split-flow/Recirculating Ventilation Air Sample Sets
Metals	2	0	5
Isocyanates	2	0	5
Organics	2	1	6
Particulate	2	2	5

without regard for the use of respirators. Clayton calculated another exposure index, $E_m(PF)$, which represents the actual inside-the-respirator breathing zone exposure index. The $E_m(PF)$ is the E_m reduced by a factor of 1,000, which is the assigned protection factor for the hood-type continuous supplied-air respirator with inner bib.

It is important to note that the Assigned Protection Factor table contained in the ANSI standard does not specify that the PF for hood-type respirators assumes that the respirator is equipped with an inner bib. Clayton contacted the Chairman of the ANSI Respirator Committee and requested clarification. The Chairman replied that the ANSI Assigned Protection Factor for the continuous-flow hood-type respirator was indeed based on a hood equipped with an inner bib.

The following subsections discuss sampling data collected before and after modification of the paint booth.

1. Organics

a. Premodification

Results of premodification air sample analyses indicated low concentrations of each of the five target chemicals. E_m values for the two sample sets were 0.07 and 0.04. Data are presented in Volume II, Appendix F.

b. Postmodification

Analysis of the air samples for the five target chemicals revealed concentrations below the applicable PELs/TLVs. The average E_m for unprotected exposure during the recirculating ventilation test series was equivalent to the E_m exposure during the baseline series. Postmodification air sampling results are shown in Table 32.

2. Metals

The applicable standard for chromium-containing paint at the time of this study was the TLV for chromic acid, which was 0.05 mg/m^3. As discussed above, the ACGIH adopted a TLV for strontium chromate in 1992. The discussion below references the chromic acid TLV as the applicable standard. The extremely low strontium chromate TLV virtually rules out its use in any recirculating system equipped with a standard filtration system.

a. Premodification

Lead and zinc were below PELs, but strontium chromate was present in concentrations resulting in potential unprotected TWA exposures above the exposure limit. However $E_m(PF)$ values are within the guideline. Results are outlined in Table 33.

b. Postmodification

Analytic results of air samples collected during recirculating ventilation indicate exposures to lead and zinc below the applicable 8-hour TWA exposure limits. However, exposure levels for strontium chromate are an order of magnitude above the TLV. The average unprotected E_m was 1.4, with an $E_m(PF)$ of 0.0014 when the protection afforded by the respirator is factored in. Results of the air sampling are presented in Table 34.

TABLE 32. POSTMODIFICATION AIR SAMPLING (8-HOUR TWA) RESULTS AND E_m FOR ORGANICS.

Date	MEK (mg/m^3)	MIBK (mg/m^3)	Toluene (mg/m^3)	*n*-Butyl Acetate (mg/m^3)	Xylenes (mg/m^3)	E_m	$E_m(PF)$
6/16/92	0.1000	5.4500	0.5750	0.0450	0.0500	0.03	0.00
6/17/92	2.8750	1.7250	0.9500	0.2750	0.1513	0.02	0.00
6/17/92	0.6750	1.1750	0.0573	0.3000	0.1851	0.01	0.00
6/18/92	0.0986	0.0814	0.0977	0.0994	0.3153	0.00	0.00
6/25/92	2.1500	15.6750	4.5750	4.3250	0.4250	0.15	0.00
6/30/92[a]	—	—	—	—	—	N.A.[b]	N.A.
Average	1.1800	4.8213	1.2510	1.0089	0.2253	0.04	0.00
PEL/TLV	590	205	188	95	434	NA[c]	NA

[a]Sample void.
[b]N.A. = Not available.
[c]NA = Not applicable.

TABLE 33. METALS BASELINE AIR CONCENTRATIONS (8-HOUR TWA).

Date	Lead (mg/m^3)	Zinc (mg/m^3)	Strontium Chromate[a] (mg/m^3)	E_m	$E_m(PF)$
4/16/91	<0.01598[b]	<0.01598	0.0440	1.20	0.0012
4/17/91	<0.01563	<0.01563	0.0421	1.15	0.0012
Average	<0.01580	<0.01580	0.0430	1.18	0.0012
PEL/TLV	0.05	10	0.05	—	—

[a]As chromium.
[b]< indicates less than the method detection limit.

TABLE 34. POSTMODIFICATION AIR SAMPLING (8-HOUR TWA) RESULTS AND E_m FOR METALS.

Date	'Lead (mg/m^3)	Zinc (mg/m^3)	Strontium Chromate[a] (mg/m^3)	E_m	$E_m(PF)$
6/22/92	0.00018	0.0013	0.0772	1.54	0.0015
6/24/92	0.00015	0.0023	0.1528	3.06	0.00306
6/25/92	0.00015	0.0049	0.0170	0.34	0.00034
6/26/92	0.00010	0.0004	0.0981	1.96	0.00196
6/26/92	0.00013	0.0008	0.0009	0.018	0.00002
Average	0.00015	0.0019	0.0692	1.4	0.0014
PEL/TLV	0.0500	10	0.05	NA[b]	NA

[a]As chromium.
[b]NA = Not applicable.

3. Isocyanates

a. Premodification

Concentrations of hexamethylene diisocyanate (HDI) for both baseline tests were below the exposure limit with an average E_m of 0.04.

b. Postmodification

Concentrations of HDI for samples collected under recirculating ventilation varied from 0.0036 to 0.2786 mg/m^3. Four of the 8-hour TWA values were above the PEL/TLV of 0.034 mg/m^3. The sample collected on 23 June 1992 indicated an HDI concentration of 0.2786 mg/m^3, considerably above the remaining sample results, which averaged 0.0203 mg/m^3. This result was obtained during painting operations involving the application of white polyurethane topcoat paint inside a comfort pallet. This data point is not representative of the normal paint booth environment since it is a space isolated from the air movement in the booth. This was the only sample set collected during the application of this type of paint.

The average unprotected E_m for this sample series was 0.53, with an $E_m(PF)$ averaging 0.0005.

G. DISCUSSION

The results of the air sampling data gathered to assess the impact of recirculating ventilation on the exposure hazard to the painter indicate that exposures to organics and HDI were within established exposure limits with or without the use of a respirator.

In general, the respiratory protection provided during this study did not provide adequate protection, based on results of air samples collected inside the respirator hood (see Volume II, Appendices F and G). As we have explained, such appears to be the result of the use of a hood-type respirator without an inner bib. The ANSI Standard for Respiratory Protection (Z88.2-1992) lists an assigned protection factor of 1,000 for a hood-type (with inner bib) continuous-flow supplied-air respirator.

Unprotected exposures to lead, zinc, and strontium chromate were in excess of the equivalent exposure index (E_m) value of 1.0 for both baseline and recirculating test modes. Strontium chromate levels in the painter's breathing zone were approximately 60 percent higher during recirculating ventilation than they were in the baseline test series. However, in both instances, the equivalent exposure index (using the chromium PEL of 0.05 mg/m^3 for strontium chromate exposure) would not be exceeded if a respirator with an assigned PF of 1,000 were used. The protected exposure indices [$E_m(PF)$] using the new TLV for strontium chromate were also within acceptable limits [$E_m(PF)$ less than or equal to 1.0].

H. CONCLUSIONS

When the proper respiratory protection is used, it appears that recirculating ventilation in the subject paint spray booth did not result in an increase in the concentration of the air contaminants studied to any degree that might have exceeded the capability of the respiratory protection provided to maintain the exposures within the exposure index guideline.

Because there can be wide ranges in operating conditions at Air Force facilities, the effects of adjusting exposure variables such as booth air flow, paint application rates, paint types, and recirculation rates should be evaluated further.

These conclusions are based on the assumption that the continuous-flow supplied-air hood-type respirator equipped with inner bib can provide and maintain its assigned protection factor of 1,000 during all modes of paint application.

Clayton was not involved in the planning or execution of the field or laboratory work associated with this project. As such, the information and documents supplied to Clayton during the course of the project were assumed to be complete, true, and correct, and were relied upon by Clayton Environmental Consultants, Inc.

SECTION VII

ECONOMIC ANALYSES

A typical VOC emission control device (ECD) can achieve a removal efficiency of at least 95 percent. However, the costs associated with installing and operating a system capable of processing the total flow volume can be enormous. The use of split-flow, recirculating, or a combination of split-flow/recirculating ventilation can significantly reduce the cost by reducing the volume of air that must be treated. Flow reduction will also decrease heating and cooling costs if the fresh intake air must be heated or cooled. This section discusses the economic advantages and benefits achievable from the use of one of these flow-reduction technologies in the control of emissions from paint spray booths.

A. CONTROL TECHNOLOGIES

The EPA handbook, Control Technologies for Hazardous Air Pollutants (Reference 16), describes the designs and costs of a variety of VOC emission control technologies, including thermal incineration, catalytic incineration, and carbon adsorption. Because the handbook notes that carbon adsorption systems may experience difficulty in controlling emission streams containing ketones, economic assessments were carried out only for thermal incineration and catalytic incineration. Ketones exothermically polymerize on the carbon bed, clogging the pores on the carbon surface, thereby reducing the effectiveness of the carbon bed. The paints used during this study contain up to 25 percent ketones in the form of MEK, MIBK, and methyl *n*-propyl ketone; in addition, the paint guns were cleaned with MEK.

The capital and operating costs for thermal and catalytic incinerators operating in conjunction with flow reduction are discussed below. Similar cost trends are expected for other treatment devices.

B. COSTS OF BOOTH MODIFICATION

The booth modification costs are based on a booth size equal to Booth 2 at Travis AFB, with a total booth flow rate of 30,000 cfm. The cost of booth modification differs for split-flow ventilation and combined split-flow/recirculating ventilation. The cost to design and install ducts for a split-flow ventilation system is estimated at approximately $20,000 for a 30,000-cfm booth. This includes the cost to design and install a transition piece in the exhaust plenum to split the flow into two chambers. The cost for a combined split-flow/recirculating ventilation system is higher due to costs associated with additional ducting, a sprinkler system, and a feedback FID control system. The cost to modify a booth to recirculating ventilation is assumed to be the same as for the combined split-flow/recirculating ventilation modification.

For the emission reduction study conducted at Travis AFB, Booth 2 was modified to accommodate either split-flow or combined split-flow/recirculating ventilation operation. The cost to install the ducts, including the purchase and installation of the transition piece, which provided the actual physical split at the exhaust face, and sprinkler system, was $30,000. This cost does not include the engineering design of the duct modification and the feedback FID control system; the total booth modification cost, including the engineering design cost, is estimated at approximately $90,000.

The design package for this project included a flow transition piece installed in the exhaust plenum to alleviate speculation regarding the split height. The cost of split-flow and combined split-flow/recirculating ventilation modifications can be decreased if the exhaust flow is split by balancing the two exhaust fans rather than by inserting a transition piece in the exhaust plenum. This option removes the cost of designing and installing the transition piece, estimated at \$30,000. This decreases the combined split-flow/recirculating ventilation modification cost to approximately \$60,000.

C. COST ANALYSIS

The economic analysis described in the EPA handbook requires emission stream data, such as flow rate, temperature, VOC concentration, and heat content. Table 35 indicates the parameters used for this analysis. Because the results of this study indicate that with split-flow/recirculating ventilation the exhaust flow rate may be safely reduced by 90 percent, the cost analysis was performed for four flow rates: 30,000 cfm (no recirculation), 15,000 cfm (50-percent recirculation), 7,500 cfm (75-percent recirculation), and 3,000 cfm (90-percent recirculation). The expected VOC concentration increases as the percent recirculation increases. The heat content of the exhaust stream was calculated for each VOC concentration.

Tables 36 and 37 list the capital costs and annual operating costs for thermal and catalytic incineration, respectively. Figures 52, 53, and 54 illustrate the dependence on flow rate of capital, operating, and 10-year-lifetime total emission control costs, respectively. Tables 36 and 37 also indicate the cost reductions achievable over a 10-year equipment lifetime. Sample economic calculations are provided in Volume II, Appendix I and detailed in Reference 16. For each of the three recirculation cases, a booth modification cost of \$60,000 is included in the total capital cost. The annual operating costs incorporate capital recovery, equipment depreciation, and property tax. A 10-year equipment life and 10-percent interest rate are assumed. The annual expenditures include operation and maintenance, utility (electricity and natural gas) costs, and catalyst replacement.

D. PAYBACK PERIOD

To determine the length of time for the return-on-investment, the payback period, in present dollars, for each ECD was calculated by equation (19):

$$\textit{Payback period} = \frac{\textit{Initial Investment}^{1}\ (\$)}{\begin{array}{c}\textit{Annualized capital saving}^{1} + \\ \textit{Annual expenditures for } 30{,}000 \textit{ scfm}^{1} - \\ \textit{Annual expenditures for modified scfm}^{1}\end{array}} \tag{19}$$

Initial investment includes the capital and booth modification costs for installing an ECD in a modified booth. Annualized capital saving is the difference in ECD capital costs between an unmodified booth and a modified booth, annualized over 10 years. Table 38 lists the payback periods for thermal and catalytic incineration for 50-, 75-, and 90-percent recirculation. The results indicate that the payback period for booth modifications is on the order of 1 to 2 years, depending on the percent recirculation and the ECD selected.

TABLE 35. EMISSION STREAM ASSUMPTIONS FOR ECONOMIC ANALYSIS.

Parameter	Assumption			
Percent recirculation	0	50	75	90
Flow rate (scfm)	30,000	15,000	7,500	3,000
Temperature (°F)	77	77	77	77
VOC concentration (ppmv)	10	20	40	100
Exhaust heat content (Btu/scf)	0.03	0.06	0.12	0.3

TABLE 36. CAPITAL, OPERATING, AND LIFETIME COSTS FOR THERMAL INCINERATION.

Percent Recirculation	Flow Rate (scfm)	Costs in Thousands of Dollars			Percent Cost Reduction Over 10-year Lifetime
		Total Capital Cost	Annual Operating Cost	Cost Over 10-year Lifetime	
0	30,000	392	383	6,104	NA[a]
50	15,000	387[b]	232	3,697	39
75	7,500	333[b]	147	2,343	62
90	3,000	275[b]	91	1,450	76

[a]NA = Not applicable.
[b]The capital costs for the split-flow/recirculating ventilation cases incorporate an estimated cost of $60,000 for the booth modifications.

TABLE 37. CAPITAL, OPERATING, AND LIFETIME COSTS FOR CATALYTIC INCINERATION.

Percent Recirculation	Flow Rate (scfm)	Costs in Thousands of Dollars			Percent Cost Reduction Over 10-year Lifetime
		Total Capital Cost	Annual Operating Cost	Cost Over 10-year Lifetime	
0	30,000	550	297	4,733	NA[a]
50	15,000	471[b]	192	3,060	35
75	7,500	368[b]	127	2,024	57
90	3,000	270[b]	81	1,291	73

[a]NA = Not applicable.
[b]The capital costs for the split-flow/recirculating ventilation cases incorporate an estimated cost of $60,000 for the booth modifications.

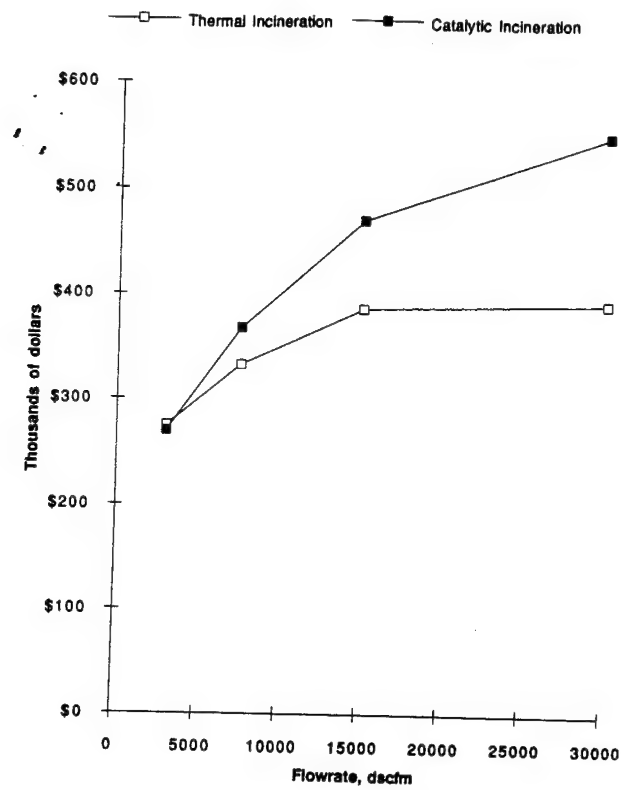


Figure 52. Capital Costs for Incineration as a Function of Exhaust Flow Rate.

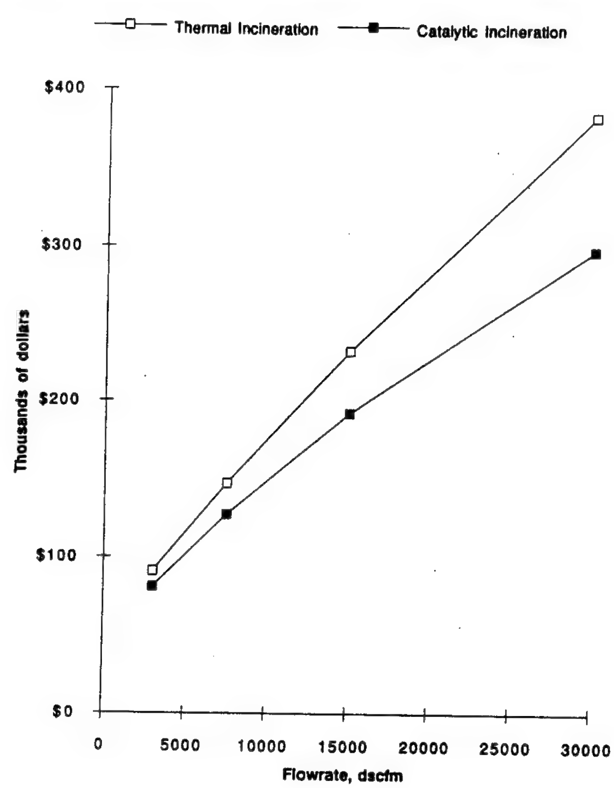


Figure 53. Annual Operating Costs for Incineration as a Function of Exhaust Flow Rate.

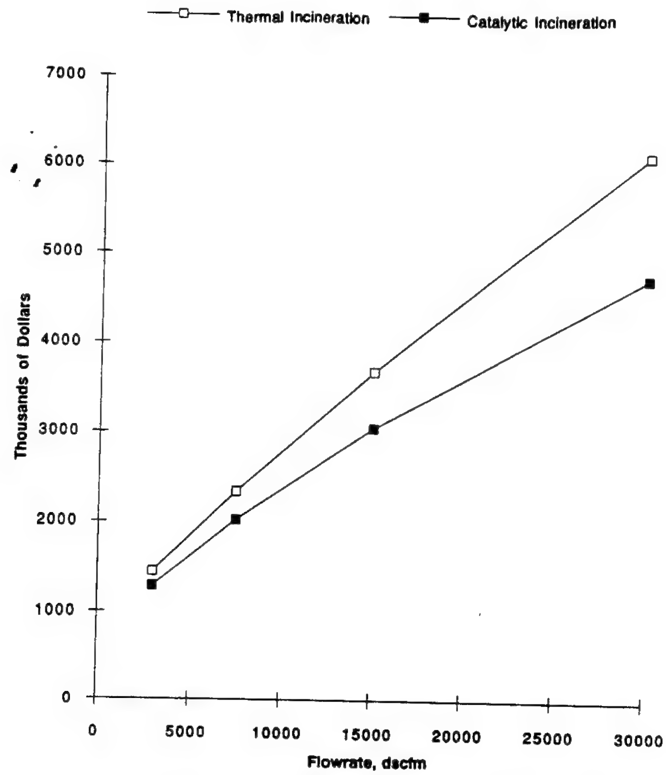


Figure 54. Total Emission Control Costs for Incineration Over 10 Years.

TABLE 38. PAYBACK PERIODS FOR MODIFYING THE BOOTH FLOW TO COMBINED SPLIT-FLOW/RECIRCULATING VENTILATION.

Percent Recirculation	Payback Period (years)	
	Thermal Incineration	Catalytic Incineration
50	2.5	4.0
75	1.4	1.8
90	0.9	1.0

SECTION VIII

ENGINEERING CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The data collected in the test efforts and the subsequent engineering evaluation lead to the following conclusions:

- Reducing the flow rate to the control device is a practical means of lowering VOC emission control costs for a paint spray booth.
- Constituent concentrations in a paint spray booth are highest in the lower half of the booth and in the vicinity of the painter.
- Split-flow ventilation has limited practicality as a flow-reduction strategy.
- The optimal split-position height and percent recirculation may be calculated using mass balance equations and the exhaust concentrations from baseline booth operations.
- For split-flow ventilation with a VOC control device attached to the high-concentration stream, the control cost and VOC capture efficiency achieved are driven by the height of the split.
- Combining split-flow and recirculating ventilation decreases the flow rate to be treated while substantially increasing the VOC capture efficiency percentage compared with split-flow ventilation alone.
- The benefit of split-flow combined with recirculating ventilation is that it will, in general, lower the concentrations of toxicants in the recirculating airstream.
- The pollutant concentrations resulting from combined split-flow/recirculating ventilation are insignificant in comparison to the concentrations due to local process conditions.
- An automatic control system can, and should, be installed to monitor the VOC concentration reentering the booth and convert the booth ventilation mode from recirculation to conventional single-pass operation if the measured VOC concentration exceeds a predetermined setpoint.
- Cost-effective elimination of VOC emissions may be achieved with a VOC control device used in conjunction with each of the following flow-reduction strategies: split-flow, recirculation, combined split-flow/recirculating ventilation.
- When recirculation of air is used in a paint spray booth, the concentrations of air contaminants do not appear to increase to a degree that would exceed the capability of proper respiratory protection.

B. IMPLEMENTATION RECOMMENDATIONS

Based upon the results of this program, we recommend that the Air Force take the following actions:

- Work with state and local regulatory agencies and EPA enforcement branches to identify split-flow and recirculating ventilation technologies falling into the Best Available Control Technology (BACT), Maximum Achievable Control Technology (MACT), and Reasonably Available Control Technology (RACT) categories, to reduce control technology capital and operating costs.

- Consider implementing VOC emission control in conjunction with split-flow or combined split-flow/recirculating ventilation.

- Conduct optimization analyses to develop the optimal flow rate reduction, split-position height, and in-booth concentration conditions.

- Examine the efficiency of different filters and filter combinations to determine a "best" particulate removal method to further decrease the levels of metals in the recirculating stream during primer coating operations.

C. DESIGN RECOMMENDATIONS

1. Steps and Criteria

Recirculating ventilation offers significant decreases in net operating costs for a spray painting facility by containing part of the risk associated with painting in the paint spray booth itself. The enabling premise underlying this study and its conclusions and recommendations for implementation is that proper design, installation, operation, and maintenance can keep the increase of risk in the painter's breathing zone to an amount so small that it is insignificant as a change to the background risk encountered under single-pass ventilation of the spray booth. To ensure that this premise is not invalidated by an inferior installation or inadequate operation and maintenance practices, we propose that the following criteria be applied during the selection of candidate sites for installation of this technology:

- The facility to be modified must include a climate control system and/or an operational or imminently planned exhaust emission control device.

- The facility to be modified must be capable of maintaining worker exposures at or below the most stringent limits, such as those specified in 29 CFR 1910.1000, for chemical constituents of materials present or in use; or, the design for construction or modification of the facility must be configured to meet these standards before the recirculation system is activated.

- Because the allowable recirculation ratio may be limited by the amount of airborne particulate matter passing through the booth filters, the actual efficiency of the particulate control system must either be measured directly or measured for an equivalent installation operating under nominally identical conditions and workloads.

- For flow splitting to be effective, concentration gradients must, on average, be present in the spraying area, and the concentration gradients from the spray booth

must be preserved downstream of the exhaust face particulate control. For example, a single waterfall control system completely mixes the exhaust, obliterating the concentration gradient; a dry filter device can maintain such a gradient.

- The ventilation system may be configured so that the organic control device is part of the recirculated stream if, for instance, it is less expensive to decontaminate and recirculate close to 100 percent of the air rather than to heat or cool outside air. In such a case, if an oxidation control technology is to be used to decontaminate the recirculated air stream, the oxygen content of the recirculated air must be monitored and supplemented with fresh air as required to maintain breathability, and the products of destruction must be analyzed upon the system's installation to ensure that toxic byproducts do not accumulate.

Once a candidate site satisfies the above conditions, the following steps should be followed to ensure that the increment to risk in the painter's breathing zone is minimized:

- Develop an initial ventilation and control design, which includes an FID or other quantitative organic-sensing device, as an air quality monitor to initiate conversion into single-pass ventilation at any time that the airborne organic concentration exceeds a preselected level.

- If the installation is to be an upgrade of an existing facility, a premodification test series should be conducted to characterize the performance of the spray facility and the particulate control system.

- Based on engineering and industrial hygiene analyses of the test series results, or on best engineering principles if a test series cannot be accomplished, calculate the maximum achievable recirculation ratio (*i.e.*, the ratio for which the standard to be applied [29 CFR 1910.1000 or more stringent standards] is exactly met — see below). Using this ratio, calculate the split height of the split duct to match the unrecirculated fraction of the exhaust stream.

- As an alternative to a premodification test series, visual observations of the concentration gradient and a material usage evaluation of VOCs can be used to estimate the appropriate recirculation ratio. A postmodification test series can be used to optimize the recirculation ratio and split height, and demonstrate worker safety.

Note that these steps do not replace any of the steps in the normal design and approval sequence followed in construction or remodeling programs.

2. Determination of Maximum Attainable Recirculation Ratio

For a recirculating-ventilation-only installation, or for a split-flow/recirculating ventilation installation whose vertical concentration gradient in the exhaust plane is unknown, the contribution to the total equivalent exposure (E_m) for each toxic constituent i is C_i/L_i (see Section II.A). During recirculation at return rate R, the individual time-weighted average concentrations in the intake air are equal to the concentrations calculated for an unmodified booth ($C_{unmod,i}$) increased by a factor of $1/(1-R)$. By selecting a value for E_m, the maximum attainable recirculation rate becomes:

$$R = 1 - \frac{1}{E_{m,recirc}} \sum_i \frac{C_{unmod,i}}{L_i} \tag{20}$$

The value of $C_{unmod,i}$ is a function of the baseline concentration at the exhaust and the efficiency of the particulate control devices. Therefore, the maximum recirculation rate (*R*) for a site is dependent on the particulate control efficiency. Figure 55 illustrates this dependence, using the baseline concentration data collected at the test site. The assumptions include a TLV for strontium chromate of 0.05 mg/m^3 and an 8-hour painting shift per work day. Intuitively, the maximum recirculation rate for organic emissions is independent of the particulate control efficiency. However, the maximum recirculation rate for metals and isocyanates, the point at which E_m = 1 for each of these constituents, is a direct function of the particulate control efficiency. The overall maximum recirculation rate for a site must be based on the limiting constituent. In this example, when the particulate control efficiency is relatively low, the metals emissions limit the maximum recirculation rate. As the particulate control efficiency is increased, the organics emerge as the limiting constituents.

If equation (20) is used to determine the maximum acceptable recirculation rate, the increase in E_m at the breathing zone due to recirculation will be insignificant compared with the E_m at the painter due to process conditions. The additional contributions from the painter, intrinsic to the paint process, result in an E_m value greater than 1 at the breathing zone. It is this intrinsic "paint cloud" that creates the requirement for respiratory equipment. The respiratory protection factor (PF) of the safety equipment must be sufficient to protect the painter from the "paint cloud" in the breathing zone. When quantifying the equivalent exposure at the painter, rather than the equivalent exposure of the intake air, it is appropriate to include in the calculation the PF for the least-protected person in the booth.

For a system that includes flow splitting, and for which reliable data are available describing the distribution of contaminants (*i.e.*, the gradient) up the exhaust face, the treatment detailed in Section II.3.C is applicable. The following calculation is accomplished by iteration on the ventilation parameters (*R* and *a*):

$$E_{m,recirc/split} = \sum_i \left[\frac{C_{unmod,i} (1 - a)}{(L_i R a)} \right] \tag{21}$$

In performing this iteration, one must keep in mind that *R* and *a* are not independent, and that one must determine *a* for each value of *R* to be evaluated. (The right-hand portion of Figure 1 illustrates the calculation graphically; the assumed value of *R* is 0.50, as indicated by the dashed line, and the value of *a* is the ratio of the shaded area to the total area under the h/[C] curve.)

The ACGIH lowered the exposure limit for strontium chromate at about the same time that this study was conducted. This action effectively eliminates the use of strontium chromate without respiratory protection because it can be extremely difficult for a ventilation process to achieve compliant exposure levels. This change in the TLV complicates the interpretation of the results of this study because particulate filtration efficiency becomes the controlling parameter.

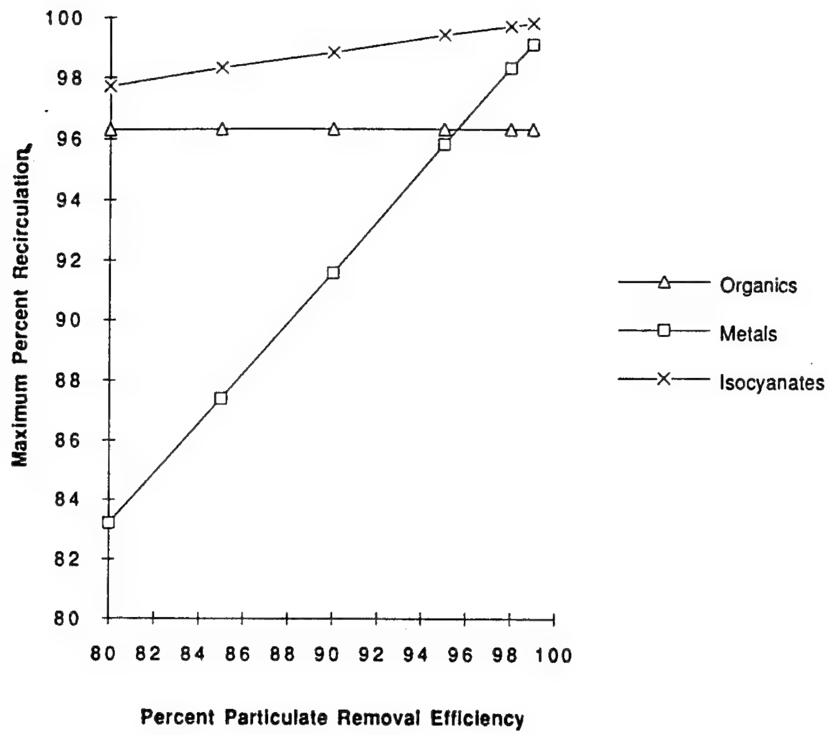


Figure 55. Dependence of Maximum Projected Recirculation on Percent Particulate Removal Efficiency — Recirculating Ventilation.

This also illustrates that a condition noncompliant in a straight-through booth cannot be improved by recirculation — that is, actual exposures are not *decreased*, they simply do not increase measurably if proper design, installation, operation, and maintenance procedures are followed.

As discussed earlier, at the time of the study the ACGIH TLV for hexavalent chromium was 0.05 mg/m^3, for which (given the booth conditions and an assumed 90-percent particulate removal efficiency) a recirculation rate of 40 to 50 percent was calculated to be the largest amount of recirculation that could be applied without exceeding the E_m = 0.25 limit on the intake air imposed by HQ AFLC/SGBE for this study (see Figure 13 in Section IV). After ACGIH imposed a strontium chromate TLV in 1992 of 0.0005 mg/m^3, the same calculation would have specified 0.5-percent recirculation, which would provide no practical benefit. That strontium chromate was used in this study is purely a result of the timing of the ACGIH action to lower the TLV. Proper application of the concept of recirculating ventilation — with or without flow splitting — requires that the materials used during recirculating ventilation be compliant under ordinary painting conditions.

Finally, some precedents have been established for the routine use of exhaust recirculation technology in manned paint facilities. Acceptance by OSHA is stated as a policy in a letter printed as Appendix A and clearly implied in two documents reproduced in Appendices B and C. Appendix B is a permanent variance issued by the State of Iowa, acting as OSHA's agent, allowing the operation of a recirculating paint facility at a John Deere installation. This action was taken in lieu of amending 29 CFR, which would be a recurrent, major undertaking required every time a new technology demonstrates performance equal to or better than methods or standards specified in 29 CFR. Appendix C contains two excerpts from the report of OSHA inspection number 102597036 (15 April 1991) of BMY Combat Systems Track Vehicles' facility,

which operates a recirculating spray painting booth. Two minor violations are identified in the painting facilities, without mention of recirculating ventilation. This illustrates the application of the *de minimis* principle defined in Appendix A, which spells out the policy of accepting technology improvements as nominal but uncited (*de minimis*) violations of 29 CFR 1910.107(d)(9), and identifies 29 CFR 1910.1000 as the applicable regulation.

REFERENCES

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4. Ayer, J. and Hyde, C., VOC Emission Reduction Study at the Hill Air Force Base Building 515 Painting Facility, EPA-600/2-90-051 (NTIS ADA 198-092), September 1990.

5. U.S. Department of Patent and Trademark Office, Patent Application Serial Number 07/609,166, January 21, 1991.

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7. NIOSH Manual of Analytical Methods, Third Edition, National Institute of Occupational Safety and Health, NTIS PB86-116266, updated May 1989.

8. Bay Area Air Quality Management District Manual of Procedures, "Standard Test Procedure 7," updated December 1989.

9. Code of Federal Regulations, Part 60 Appendix A, Test Methods, 1989.

10. OSHA 42 Airborne Di-isocyanate Sampling and Analysis Protocol, Occupational Safety and Health Administration, Carcinogen and Pesticide Branch, OSHA Analytical Laboratory, February 1983, unpublished.

11. Test Methods for Evaluating Solid Waste, SW-846 Draft Method 0012, U.S.Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, July 1992.

12. Industrial Ventilation—A Manual of Recommended Practices: Testing of Ventilation Systems, 20th Edition, Chapter 9, American Conference of Governmental Industrial Hygienists, 1988.

13. Coyne, L. and Moore, G., Toluene Diisocyanate (TDI) Emissions: An Evaluation of Monitoring Methods and Filtration Substrate for Stacks, 83rd Annual Meeting and Exhibition of the Air and Waste Management Association, Pittsburgh, PA, June 1990.

14. Code of Federal Regulations, Title 29, Part 1910.252, July 1991, "Welding, Cutting, and Brazing."

15. Perry, R., and Green, D. Perry's Chemical Engineers' Handbook, Sixth Edition, 1984.

16. Sink, M.K., Handbook: Control Technologies for Hazardous Air Pollutants, EPA/625/6-91/014 (NTIS PB92-141-373), U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, OH, June 1991.

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APPENDIX A

OSHA RULING ON PAINT BOOTH EXHAUST GAS RECIRCULATION

U.S. Department of Labor

Occupational Safety and Health Administration
Washington, D.C. 20210

Reply to the Attention of:

JAN 16 1990

Susan R. Wyatt, Chief
Chemicals and Petroleum Branch
Emission Standards Division
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

Dear Ms. Wyatt:

This is in response to your letter of October 31, 1989, concerning the Occupational Safety and Health Administration (OSHA) regulation at 29 CFR 1910.107(d)(9) which prohibits the recirculation of exhaust air from spray finishing operations. Please excuse the delay in response.

As you are aware, 29 CFR 1910.107 was adopted from the NFPA 33-1969, Standard for Spray Finishing Using Flammable and Combustible Materials. The NFPA-33 standard is explicitly a fire and explosion safety standard. Therefore, the OSHA standard at 29 CFR 1910.107 pertains to the prevention of workplace fire and explosion hazards and does not pertain to health considerations.

Although the NFPA has updated their standard since the 1969 edition, OSHA has not. As a result, the current NFPA 33-1985, Spray Application Using Flammable and Combustible Materials, reflects the most up to date state of the art concerning the prevention of fire and explosion hazards during spray finishing operations.

Under an OSHA policy for "de minimis violations", employers are encouraged to abide by the most current consensus standard applicable to their operations, rather than with the standard in affect at the time of the inspection when the employer's action provides equal or greater employee protection. De minimis violations are violations of existing OSHA standards which have no direct or immediate relationship to safety or health. Such violations of the OSHA standards result in no citation, no penalty and no required abatement. A copy of the OSHA policy for de minimis violations is enclosed.

Employers who fully comply with the specifications and requirements of the NFPA 33-1989, concerning the recirculation of exhaust air to an occupied spray booth, would not be cited under 29 CFR 1910.107(d)(9) under the policy for de minimis violations. However, the quality of the respirable air in the booth must comply, at a minimum, with the requirements set forth by 29 CFR 1910.1000 which establishes permissible exposure limits (PEL's).

If we may be of further assistance, please contact us.

Sincerely,

Thomas J. Shepich

Thomas J. Shepich, Director
Directorate of Compliance Programs

6. De Minimis Violations. De minimis violations are violations of standards which have no direct or immediate relationship to safety or health. Whenever de minimis conditions are found during an inspection, they shall be documented in the same way as any other violation but shall not be included on the citation.

a. Explanation. The criteria for finding a de minimis violation are as follows:

(1) An employer complies with the clear intent of the standard but deviates from its particular requirements in a manner that has no direct or immediate relationship to employee safety or health. These deviations may involve distance specifications, construction material requirements, use of incorrect color, minor variations from recordkeeping, testing, or inspection regulations, or the like.

EXAMPLES: (a) 29 CFR 1910.27(b)(1)(ii) allows 12 inches as the maximum distance between ladder rungs. Where the rungs are 13 inches apart, the condition is de minimis.

(b) 29 CFR 1910.28(a)(3) requires guarding on all open sides of scaffolds. Where employees are tied off with safety belts in lieu of guarding, the intent of the standard is met; and the absence of guarding is de minimis.

(c) 29 CFR 1910.217(e)(1)(ii) requires that mechanical power presses be inspected and tested at least weekly. If the machinery is seldom used, inspection and testing prior to each use is adequate to meet the intent of the standard.

(2) An employer complies with a proposed standard or amendment or a consensus standard rather than with the standard in effect at the time of the inspection when the employer's action provides equal or greater employee protection.

(3) An employer's workplace is at the "state of the art" which is technically beyond the requirements of the applicable standard and provides equivalent or more effective employee safety or health protection.

b. Professional Judgment. Maximum professional discretion must be exercised in determining the point at which noncompliance with a standard constitutes a de minimis violation.

c. Area Director Responsibilities. Area Directors shall ensure that the de minimis violation meets the criteria set out in B.6.a.

APPENDIX B

PERMANENT VARIANCE ISSUED BY IOWA FOR A JOHN DEERE RECIRCULATING PAINT FACILITY

DEERE & COMPANY

JOHN DEERE ROAD, MOLINE, ILLINOIS 61265 U.S.A

To: E. J. Filby, Safety Director, Des Moines

From: E. O. Shaw, Law

Date: 10 September 1984

Subject: Variance No. 68 - John Deere Des Moines Works

This is your copy of the permanent variance grant for operation of the paint booths.

Please post a copy and deliver one to the Union.

Applying for and obtaining these variances has been one of my most satisfying tasks at Deere & Company.

EOS/bh
Att.

c + att C. A. Peterson, Safety

RECEIVED
SEP 1984

OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL # of pages ► 4

To Joe Wander	From Chuck Darvin
Dept./Agency	Phone # 919/541-7633
Fax # 904/283-6286	Fax #

NSN 7540-01-317-7368 5099-101 GENERAL SERVICES ADMINISTRATION

IOWA BUREAU OF LABOR

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

In the matter of John Deere Des Moines Works of Deere & Company	))))))	Variance No. 68

I. BACKGROUND

On July 30, 1982, John Deere Des Moines Works of Deere & Company, Highway 415 North, Ankeny, Iowa, made application for a permanent variance. The application was made pursuant to Iowa Code section 88.5(3) and 530-5.8(88)IAC and requested a variance from 530-10.2(88)IAC, reference 1910.94(c)(5), 1910.94(c)(6), 1910.94(c)(7), and 1910.107(d)(2), and the following substances listed in 1910.1000: lead, chormate, VM & P naphtha, toluene, mineral spirits, xylene, D-100 (Trimethyl benzene), D-150 (Tetramethyl benzene), and cellosolve acetate and 1910.1025. The application requests approval for a recirculating air system for a paint booth at its facility. An Interim Variance was issued on September 23, 1982.

The only worksite covered by the application is located at the John Deere Des Moines Works, Ankeny, Iowa.

The applicant has certified that employees who would be affected by the variance have been notified of the application by posting and by delivering a copy to the employees' representative. Notice has also been given to the employees informing them of their right to petition the Commissioner of Labor for a hearing. Iowa Bureau of Labor staff have discussed the application and relevant procedures with the employees' representatives.

II. APPLICATION

The application provides for the recirculating of air for the paint booth instead of the existing once-through system. The applicant states that it will provide protection to employees which is equal to or greater than that required by the standards. Employees will be required to wear positive pressure air hoods provided with purified compressed air which is free from oil, water or odor and shall meet at least the requirements of the specifications for Grade D breathing air as described in Compressed Gas Association Commodity Specifications G-7.1-1966. Exhaust air will be filtered through water to remove particulates. Measures will be taken to prevent drift from the paint booth to other work spaces. Procedures and equipment will assure that solvent concentrations in the booth do not exceed twenty-five (25) percent of the L.E.L. (lower explosive limit). Flashback protection approved by Factory Mutual is provided.

The applicant states that the operation and procedures contemplated in the application will permit the utilization of an innovative technique of the sort contemplated by Iowa Code section 88.1. It is further stated that the concept offers a unique opportunity to reduce emissions from the spray booth thereby improving the quality of the air in the environment.

Testing at the facility has indicated that the methods proposed by the applicant does not further expose employees to overexposures of toxic substances. While the employer requires employees to wear respirators, such practice is only permitted until technological advancements will allow for the installation of engineering controls to permit employees to work in the spray booth without respirators.

III. PROCEDURES

Any interested person may view a copy of this application and supporting materials in the office of the Iowa Bureau of Labor, 307 East 7th, Des Moines, Iowa. Walter H. Johnson, Deputy Commissioner, is the contact person.

IV. ORDER

It appears from the application for a permanent variance and testing and observations of the equipment and procedures, that the procedures, practices, methods, and operations proposed to be instituted by the applicant will provide safeguards against injury or illness to employees as contemplated by the standards.

THEREFORE, IT IS ORDERED pursuant to the authority of Iowa Code section 88.5(3) and 530-5.8(88)IAC, that the applicant, John Deere Des Moines Works of Deere & Company, is granted a Permanent Variance.

The applicant shall comply with all other provisions of the Iowa Occupational Safety and Health Standards.

The applicant shall give notice to all affected employees of the terms of this Permanent Variance Order by the same means required to inform them of this application.

The Permanent Variance Order shall be effective as of the 17th day of August, 1984.

Allen J. Meier
Commissioner of Labor

APPENDIX C

EXCERPTS FROM AN OSHA INSPECTION REPORT

Occupational Safety and Health Administration

Citation and Notification of Penalty

U.S. Department of Labor - OSHA
Progress Plaza
49 North Progress Avenue
Harrisburg, PA 17109

3. Issuance Date	4. Inspection Number
08/28/91	102597036
5. Reporting ID	6. CSHO ID
0316700	W2359
7. Optional Report No.	8. Page No.
270	8 of 22

Penalties Are Due Within 15 Days of Receipt of This Notification Unless Contested (See enclosed Booklet)

1. Type of Violation(s)	2. Citation Number
Serious	01

The violation(s) described in this Citation are alleged to have occurred on or about the day the inspection was made unless otherwise indicated within the description given below.

10. Inspection Date(s): 4/15/91 - 4/25/91

11. Inspection Site:

Bair Station Road
York, PA 17405

9. To:

BMY Combat Systems Track Vehicles
and its successors
P.O. Box 1512
York, PA 17405

This Section May Be Detached Before Posting

THE LAW REQUIRES that a copy of this Citation be posted immediately in a prominent place at or near the location of violation(s) cited below. The Citation must remain posted until the violations cited below have been abated, or for 3 working days (excluding weekends and Federal holidays), whichever is longer.

This Citation describes violations of the Occupational Safety and Health Act of 1970. The penalty(ies) listed below are based on these violations. You must abate the violations referred to in this Citation by the dates listed below and pay the penalties proposed, unless within 15 working days (excluding weekends and Federal holidays) from your receipt of this Citation and penalty you mail a notice of contest to the U.S. Department of Labor Area Office at the address shown above. (See the enclosed booklet which outlines your rights and responsibilities and should be read in conjunction with this form.) You are further notified that unless you inform the Area Director in writing that you intend to contest the Citation or proposed penalties within 15 working days after receipt, this Citation and the proposed penalties will become a final order of the Occupational Safety and Health Review Commission and may not be reviewed by any court or agency. Issuance of this Citation does not constitute a finding that a violation of the Act has occurred unless there is a failure to contest as provided for in the Act or, if contested, unless the Citation is affirmed by the Review Commission.

12. Item Number / 13. Standard, Regulation or Section of the Act Violated	14. Description	15. Date by Which Violation Must Be Abated	16. Penalty
7c 29 CFR 1910.24(f):	The treads of fixed stairs were not reasonably slip-resistant with a nonslip finish on nosings: (a) Building 12, East End - G-49 horizontal turning machine had fixed stairs that had wooden treads without a non-slip finish, on or about April 16, 1991.	09/18/91	
8 29 CFR 1910.107(c)(2):	Open flames or spark producing equipment were located in the spraying areas: (a) Building #4, Painting Area - Fan not approved for a Class 1, Group D location, on or about April 16, 1991.	09/18/91	1125.0

17. Area Director Robert M. Fink

18. Last Pg

NOTICE TO EMPLOYEES — The law gives an employee or his representative the opportunity to object to any abatement date set for a violation if he believes the date to be unreasonable. The contest must be mailed to the U.S. Department of Labor Area Office at the address shown above within 15 working days (excluding weekends and Federal holidays) of the receipt by the employer of this Citation and penalty.

EMPLOYER DISCRIMINATION UNLAWFUL — The law prohibits discrimination by an employer against an employee for filing a complaint or for exercising any rights under this Act. An employee who believes that he has been discriminated against may file a complaint no later than 30 days after the discrimination with the U.S. Department of Labor Area Office at the address shown above.

Total Penalty for This Citation

Make Check or Money Order Payable to: "DOL-OSHA"

Indicate Inspection Number on Remittance

EMPLOYER RIGHTS AND RESPONSIBILITIES — The enclosed booklet outlines employer rights and responsibilities and should be read in conjunction with this notification.

ORIGINAL

CITATION AND NOTIFICATION OF PENALTY

OSHA-2 (1/84)

U.S. Department of Labor
Occupational Safety and Health Administration

Citation and Notification of Penalty

U.S. Department of Labor - OSHA
Progress Plaza
49 North Progress Avenue
Harrisburg, PA 17109

1. Type of Violation(s)	2. Citation Number
Other	02

The violation(s) described in this Citation are alleged to have occurred on or about the day the inspection was made unless otherwise indicated within the description given below.

3. Issuance Date	4. Inspection Number
08/28/91	102597036
5. Reporting ID	6. CSHO ID
0316700	W2359
7. Optional Report No.	8. Page No.
270	6 of 10

10. Inspection Date(s): 4/15/91 - 4/25/91

11. Inspection Site: Bair Station Road
York, PA 17405

Penalties Are Due Within 15 Days of Receipt of This Notification Unless Contested (See enclosed Booklet)

This Section May Be Detached Before Posting

9. To:
BMY Combat Systems Track Vehicles
and its successors
P.O. Box 1512
York, PA 17405

THE LAW REQUIRES that a copy of this Citation be posted immediately in a prominent place at or near the location of violation(s) cited below. The Citation must remain posted until the violations cited below have been abated, or for 3 working days (excluding weekends and Federal holidays), whichever is longer.

This Citation describes violations of the Occupational Safety and Health Act of 1970. The penalty(ies) listed below are based on these violations. You must abate the violations referred to in this Citation by the dates listed below and pay the penalties proposed, unless within 15 working days (excluding weekends and Federal holidays) from your receipt of this Citation and penalty you mail a notice of contest to the U.S. Department of Labor Area Office at the address shown above. (See the enclosed booklet which outlines your rights and responsibilities and should be read in conjunction with this form.) You are further notified that unless you inform the Area Director in writing that you intend to contest the Citation or proposed penalties within 15 working days after receipt, this Citation and the proposed penalties will become a final order of the Occupational Safety and Health Review Commission and may not be reviewed by any court or agency. Issuance of this Citation does not constitute a finding that a violation of the Act has occurred unless there is a failure to contest as provided for in the Act or, if contested, unless the Citation is affirmed by the Review Commission.

12. Item Number / 13. Standard, Regulation or Section of the Act Violated	14. Description	15. Date by Which Violation Must Be Abated	16. Penalty
8 29 CFR 1910.29(a)(4)(ii):	Scaffold caster(s) were not provided with a positive wheel and/or swivel lock to prevent movement: (a) Building #7 - One (1) wheel lock was missing from manually propelled mobile scaffold, on or about April 16, 1991.	09/05/91	0.0(
9 29 CFR 1910.107(c)(6):	Electrical wiring and equipment outside of but within 20 feet of spraying area(s), and not separated there from by partitions, did not conform to the provisions for Class 1, Division 2, hazardous locations: (a) Building #4, Spraying Area, Outside Door - Electric wiring was not of the explosion proof type, on or about April 15, 1991.	09/18/91	0.0(

17. Area Director for / Robert M. Fink

18. Last Pg

Total Penalty for This Citation

Make Check or Money Order Payable to: "DOL-OSHA"

Indicate Inspection Number on Remittance

NOTICE TO EMPLOYEES — The law gives an employee or his representative the opportunity to object to any abatement date set for a violation if he believes the date to be unreasonable. The contest must be mailed to the U.S. Department of Labor Area Office at the address shown above within 15 working days (excluding weekends and Federal holidays) of the receipt by the employer of this Citation and penalty.

EMPLOYER DISCRIMINATION UNLAWFUL — The law prohibits discrimination by an employer against an employee for filing a complaint or for exercising any rights under this Act. An employee who believes that he has been discriminated against may file a complaint no later than 30 days after the discrimination with the U.S. Department of Labor Area Office at the address shown above.

EMPLOYER RIGHTS AND RESPONSIBILITIES — The enclosed booklet outlines employer rights and responsibilities and should be read in conjunction with this notification.

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